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Measuring Method for Large Aspherical Surfaces with Holographic Optical Elements

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Synopsis

Measuring method for the shape of large aspherical surfaces is reported. The method is an interferometory using holographic optical elemets. The standard plate is made by recording the interference fringe pattern between the parallel reference beam and the reconstructed wave front from the master zone plate which is drawn by an electron beam drawing machine with off-axis optical arrangement. The standard plate is reconstructed by the conjugate beam and creates the standard wave front in a modified Twyman-Green interferometer. Insufficient parallelism of commercial hologram plates can be compensated by a new optical layout. It is also easy to duplicate the standard plate. Some experimental results are also presented.

KEYWORDS: interferometry, holographic optical element, aspherical lens, toric lens, hologram, diffraction grating

1. Introduction

Aspherical optical elements are used as important devices for cameras, laser beam printers, pick-up lens of optical disk memory drives and so on. Not only rotationally symmetric lenses but also non-rotationally symmetric devices have been investigated and used for commercial products. Their sizes are becoming larger and the quality is getting much better. A Measuring method for the aspherical optical elements is a key technology, especially for mass production. Design of aspherical surface has been advanced by computer technologies. Tooling with computer controlled turning with diamond bite is also developed recently. Measuring methods are developed too but they are not enough for mass-production because of speed and the limit of size. The authors propose a simple and universal interferometry using a holographic optical element for this purpose[1,2,3].

2. Conventional methods

There are methods by which aspherical surfaces can be measured. It is difficult for mechanical tracers to measure a surface all at once. However it takes hours to trace all surface of sample lens, this method is generally applied only for rotational symmetric surfaces. Null lens method can measure all surface at once. Fig.1 shows the interferometer using a null lens.

This method is simple and rapid enough for mass production but it is very difficult to manufacture a null lens only for rotational symmetric surfaces and almost impossible for non rotationally symmetric ones. Useful interferometry with a master zone plate (MZP) that is a computer generated hologram for measuring an aspherical lens was reported.[4] The MZP is used instead of the null lens in Fig. 1.

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The MZP which is a phase diffraction grating, has a computer generated grating pattern drawn by an electron-beam drawing machine or by a laser-beam drawing machine.[5] The pattern is calculated to create the desired wave fronts which match the shape of sample surface.[6,7] This method is suitable for small size lenses but is not good for a convex surface of large diameter because the diameter of a MZP must be larger than that of the samples. Much time is required to draw many diffraction patterns on the material by a drawing machine, especially for an electron-beam drawing machine; this machine is usually used to draw photo-mask patterns for the IC process. For this purpose the actual drawn area is very small, i.e., less than five percent of the scope of the drawn area. To make the diffraction grating in the IC process, it is half the scope, which is why it takes much time and is actually impossible to draw such pattern.

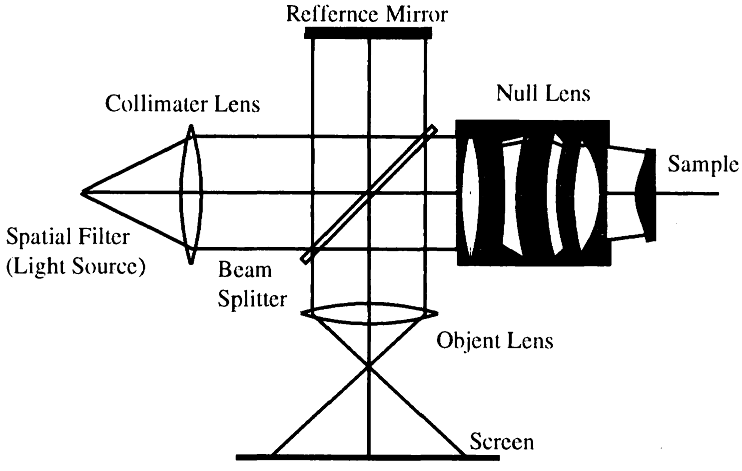

Fig. 1 Twiman-Green interferometer with a null lens

3. The Interferometer System

A new interferometer that can measure large convex aspherical surfaces is proposed in this section. The proposed method uses a holographic optical element called a slave zone plate (SZP) that is formed by interference pattern of a wave front reconstructed by a MZP with a plane wave front in order to have a larger size than that of the samples. Fig. 2 shows the optical layout for recording an SZP with MZP.

Merits of this method are that large convex aspherical surfaces can be measured, that the MZP is precise enough because it is drawn by electron beam drawing machine and that duplication of SZP is easy because it is recorded by holographic method.

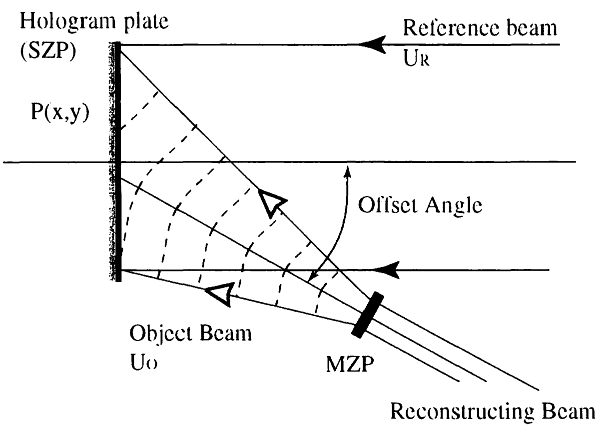

Fig. 2 Optical layout for recording a SZP

4. Slave Zone Plate

Fig. 3 shows the wave front perpendicular to the aspherical surface and the zone plate. The pattern on the zone plate should have the interference pattern of the reference beam perpendicular to the zone plate U_R and the object beam U_O perpendicular to the aspherical surface.

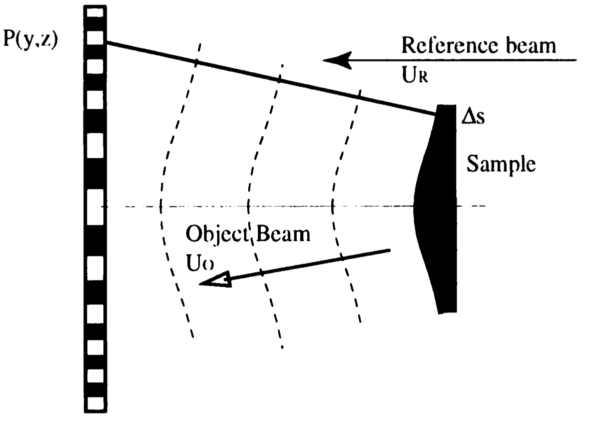

Fig. 3 Calculation of the diffraction pattern of MZP

The diffraction pattern of MZP should be calculated as follows.

$$T_{(y,z)} = \pi / 2 \qquad (1)$$

where $(m - 1/4)\lambda \leq L < (m + 1/4)\lambda$ and

$$T_{(y,z)} = 0 \qquad (2)$$

where $(m - 1/4)\lambda < L \leq (m + 3/4)\lambda$

where $T_{(y,z)}$ is the delay of the phase at $P_{(y,z)}$ and m is integer.

The pattern is drawn by an electron-beam drawing machine. The plate and chemical treatment are as same as conventional photo-mask and IC process. The plate can be used for MZP as it is because the photo-resist material is stable under room temperature and humidity. Though the actual drawing area of the scope is 50% it is not difficult to draw a small diameter pattern, for example, ten millimeters. The MZP is reconstructed by the parallel beam and the propagating wave front goes to a hologram plate as shown in Fig. 2. The axis of the wave front has a certain incident angle between zero and 90 degrees. On the other hand, the parallel reference beam goes onto the hologram plate perpendicularly. The interference fringe between the two wave fronts is recorded on the hologram plate. The plate is developed and fixed or bleached as in the usual process. Then, the hologram plate becomes the SZP.

If the MZP is axially aligned in the reference beam, the SZP does not have all the required patterns because some holders of MZP interrupt the reference beam.

5. Twyman-Green Interferometer

The SZP is arranged on a Twyman-Green interferometer and reconstructed by the conjugate parallel beam as shown in Fig. 4. An interference fringe pattern of the difference between the sample surface and the designed shape should be observable. But the optical path of the object beam that passes through the SZP two times is different from that for the ideal conjugate reconstruction because the parallelism of the SZP is not sufficient for interferometry. The SZP which is a commercial hologram plate does not have perfect parallelism that is around one or two ramda comparable with a plate glass used for a window. One solution is to use a well-polished optical glass plate, however, a plate with photosensitive materials on it is not commercially available. Of course photo mask plates for IC process are available but they do not match for mass production because they do not have sensitivity at He-Ne laser and they cost much.

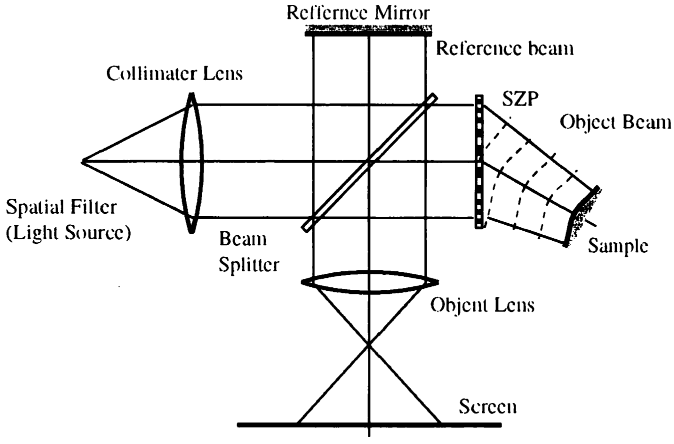

Fig. 4 Twyman-Green Interferometer with

6. Modified Twyman-Green Interferometer

The authors propose a modified Twyman-Green interferometer to eliminate the aberration from the difference of the optical path. The object beam from the SZP has some distortion due to the plate non-uniformity in addition to the aberration of the sample surface itself. The aberration can be canceled by this optical layout as follows. The reference beam has the same distortion as the object beam because the reference beam passes through the SZP two times in the same way as the object beam does. Thus the zero-th order beam of the SZP must be the reference beam as shown in Fig. 5.

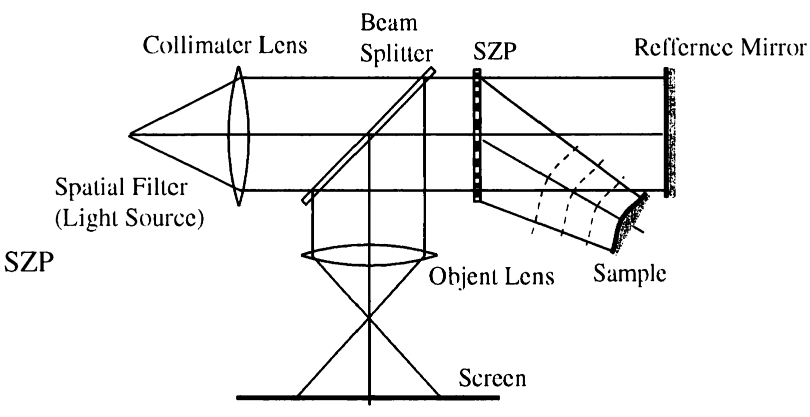

Fig. 5 Modified Twyman-Green Interferometer with SZP

7. Experimental Results

To confirm the effectiveness of the method a SZP is recorded as shown in Fig. 2 without the MZP. The SZP is a simple grating made by two parallel beams. The beams go onto the sensitive surface. The surface quality of mirrors or lenses used in this experiment was approximately 1/10.

The SZP is arranged in the interferometers as shown in Figs. 4 and 5. The observed interference fringes are shown in Figs. 6 and 7, respectively. Aberration caused by thickness variations of the SZP substrate is observed in Fig. 6. Though some spherical term remains in the fringe it is confirmed that the aberration can be compensated by this method as shown in Fig. 7.

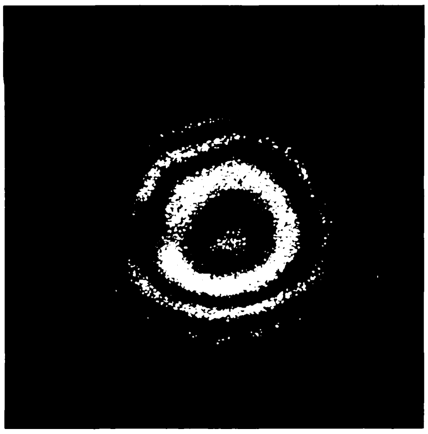

Fig. 6 Interferance pattern by Twyman-Green interferometer with SZP

Fig. 7 Compensated interferance fringe by modified Twyman-Green interferometer with SZP

As an actual example, a convex toric surface which has 18.2mm and 76.2mm radii and is 12mm by 80mm in size is measured. Fig. 8 shows the toric lens. The MZP pattern drawn by an electron-beam drawing machine is shown in Fig. 9. It is set 1mm distant from the axis of the 18.2mm radius in the direction of the toric surface. The electron-beam scanning area is only 1mm square. Larger ranges are drawn after moving a photosensitive plate by the mechanical stage. There are gaps every 1mm on the MZP because the mechanical stage of our drawing machine does not have sufficient accuracy.

The result is shown in Fig. 10. The observed area is approximately a 10mm square of the central part. The asphericity of the measured area is more than 0.6mm. A certain area of the toric surface is observed at a time. The interference fringe has larger aberration than ordinary spherical lenses or rotationally symmetric aspherical lenses. It is not yet clear whether the aberration is due to the accuracy of the sample itself or the accuracy of a MZP.

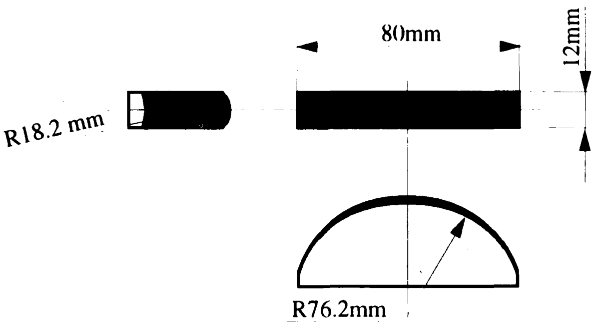

Fig. 8 Toric lens

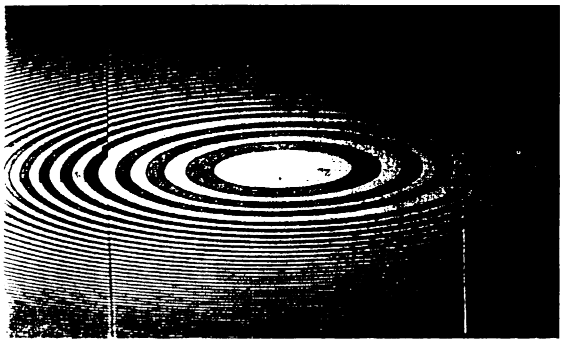

Fig. 9MZP for toric lens

Fig. 10 Interferance fringe of a torice surface

8. Conclusions

The authors investigated a new interferometry for measuring large aspherical surfaces including non rotationally symmetric surfaces. A holographic optical element on which the wave front reconstructed from the MZP is recorded is applied to the interferometer. The MZP is prepared by the well-known IC process. The interferometry can be applied to check aspherical surfaces of large diameter, and the measurable size is limited by the size of components used in the interferometer but not by the size of the MZP. Commercial hologram plates with insufficient parallelism are available for a SZP because the proposed simple layout of the interferometer can eliminate thickness variations in the SZP substrate. This is achieved by the modified off-axis Twyman-Green interferometer. It is also easy to make replicas.

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