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SHEARING INTERFEROMETER USING FOUR GRATINGS

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Abstract: This paper describes a shearing interferometer with four diffraction gratings for dividing light waves. It allows us to use an extended white light source. This feature of the interferometer is discussed and demonstrated by experiments. By constructing the interferometer for testing transparent object, phase distribution of the light wave passing through an optical lens is measured with a halogen lamp source. By modifying it for the reflecting object, profile of a curved mirror is measured.

Keywords: Shearing Interferometer, Grating, Phase Measurement

1 INTRODUCTION

A shearing interferometer is a useful tool for testing mirrors and lenses [1,2]. It is stable because the two interfering waves travels almost the same path. In most shearing interferometers, we use a coherent laser light source. However, coherent waves are likely to produce disturbing coherent noises caused by undesired light waves reflected by optical components or scattered by dust in the light paths. They will be reduced if we can adopt an extended white light source for the interferometer. Then, the inspection can be done in a more practical conditions.

In this paper, we propose a shearing interferometer with four gratings, which allow us to use an extended white light source. The basic principles are described and some experiments are shown. In the experiments, we measured phase distributions of the waves which pass through a lens and are reflected by a mirror.

2 PRINCIPLE

2.1 OPTICAL SYSTEM

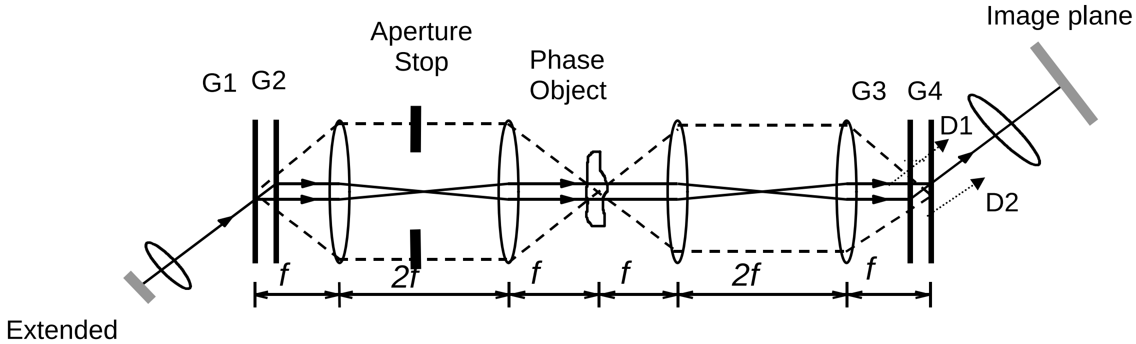

Figure 1. Optical System

The basic configuration of the interferometer is shown in Fig. 1, where G_1, G_2, G_3 and G_4 are gratings with the same grating constant. The spacing between G_1 and G_2 is the same as the spacing between G_3 and G_4. The first pair of gratings, the object and the second pair of gratings are conjugate to each other. A light beam incident on the first grating pair is converted into a pair of slightly displaced (sheared) light beams after passing through it. Both of the sheared beams pass through the object and are recombined after they pass through the second pair of gratings. Two recombined beams interfere with each other. One of the interfering beams is diffracted by the grating G_1 and G_3 and the other is diffracted by G_2 and G_4. As the paths are similar, path difference between these beams are zero when the object is absent. Thus the two beams interfere with each other even if we use incoherent light.

Interference fringes appear on the image plane when a transparent object is inserted. The interference fringes correspond to the phase difference between the two sheared beams. From the interferometric data we can calculate the phase change caused by the object.

2.2 ACHROMATIC FEATURE

In the configuration shown in Fig.1, amount of shear s is denoted by

s=*S* tan*è* (1)

where *S* is separation of the paired gratings and *è* is the incident angle on the grating. When period of grating is *d* and the light wavelength is *ë* ,

d sin*è* = *ë* (2)

For a small angle *è* ,*s* is approximated as

s=*S* *ë*/ *d* (3)

When an object is inserted, the path difference *ÄL* between the two sheared rays are produced. It is approximated to be linearly dependent on the amount of shear. If we denote the linear coefficient as *A*,

ÄL=*As* (4)

Intensity of the interfered light is determined by the phase difference between the two interfering waves. The phase difference *ÄÔ* is expressed as

ÄÔ = 2ð AS/d (5)

This formula means that the phase difference is independent of the wavelength. Thus the contrast of the fringes in the present interferometer is good even if it has the white light source.

The light source is extended and it is conjugate to the object. Therefore a point in the light source corresponds to a point in the object. A light ray radiated in a different direction from a point in the light source passes through the point in the object in the different direction. However, the shear is the same for all rays. The path difference may be different for the sheared rays travelling in the different direction. Thus the path difference *ÄL* may be approximated as

ÄL=*a (1 + b Äè) s* (6)

where *Äè* is the angle difference from the central ray. As shown in this formula, the path difference is different for different incident angle. Thus, contrast of interference fringes degrades if rays with wide range of angles are used for imaging. However, variation of path difference is small for small shear and we can use wide range of angles for a shearing interferometer of small shear. We insert an aperture stop for restricting the incident angle.

2.3 FRINGE CONTRAST

In the image plane two images D_1 and D_2 are superposed in addition to the required sheared image. Image D_1 is the one diffracted by G_2 and G_3 and image D_2 is the one diffracted by D_1 and D_4. Images D_1 and D_2 are displaced by ±*s* compared with the required image in the image plane. As we use an incoherent white source, the images D_1 and D_2 do not interfere with the required sheared image. Because all the four superposed rays are diffracted twice by the gratings, they have the same intensity. Then the fringe intensity *I* can be calculated as

I =2I_0+ I_0 *cos(ÄÔ + ä)* (7)

where I_0 is the intensity of each ray and *ä* is uniform phase difference between the sheared beams introduced by the structure of the interferometer. Contrast of the fringe is 1/2 and degradation of contrast is not so severe.

2.4 PHASE CALCULATION

As the phase difference of the shearing interferometer is small especially when the shear is small, we have to measure the phase difference in the order much smaller than *2ð*. For the purpose use phase shifting method. Deliberate phase shifts between the two sheared beams are introduced by displacing one of the paired gratings. Displacement of the grating by u causes the phase shift *ä*

$$ä = 2ð\, u/d, \qquad (8)$$

where *d* is the period of the grating. This phase shift is also independent of wavelength.

Four fringe intensities I_m (m = 1, 2, 3, 4) corresponding to four phase shifts

$$ä_m = 2ð\, m/4 \qquad (m = 1, 2, 3, 4) \qquad (9)$$

are measured. Phase difference due to the object is calculated as

$$ä\, Ô = \tan^{-1}\{(I_2 - I_4)/(I_1 - I_3)\} \qquad (10)$$

Calculated phase *ä Ô* is the phase difference between the two beams displaced by *s.* If phase difference at a position (x,y) on the image is denoted by *ä Ô* (x,y) and the shear is assumed in the x direction, we can calculate phase *Ô* of the ray at the point (*ns* , y) by integrating the phase difference:

$$Ô\,(ns,y) = Ô\,(0, y) + Ó\, ä\, Ô\,(ns,y) \qquad (11)$$

3 EXPERIMENTS

As a light source we use a diffuser which is illuminated by a 150 W halogen lamp. The gratings is binary phase gratings with period of 8µm formed on glass plates of 1.1mm thickness. The nominal angle of incidence is *è*=3.9°, and the divergence of the incident angles is ±2° from the nominal angle. The spacing between the gratings is 2.2 mm and the amount of shear is 100µm for a light wave of wavelength 550 nm. Focal lengths of lens L_1, L_2, L_3, and L_4 are 120 mm. Diameter of measurement area is 15 mm. Image is detected by a CCD camera and its output is fed into an image processor. Phase shifts are introduced by translating the fourth grating. For the purpose a translation stage using a parallel spring is constructed and it is moved by a micrometer.

Figure 2 shows interference fringes obtained with a spherical lens as an object. The lens has a focal length of 333 mm. Diameter of the measurement area is 15mm. The intensity distribution along a horizontal line (y axis) of the fringe pattern is shown in Figure 3. The contrast is about 0.4 which is not so worse than the theoretical prediction.

By shifting the phase, we can obtain four patterns with translated fringes similar to Figure 2. From the patterns phase difference can be calculated with Eq. (10). Due to the non-uniformity of the optical system, the phase difference is not uniform even when no object is inserted. Therefore we compensate the phase difference by subtracting the initial phase difference from the measured phase difference. The phase distribution is obtained by integrating the compensated data using Eq. (11) and it is converted into path length. The resultant path length distribution is shown in Fig. 4 (a) and (b). In Fig. 4(b) path length distribution along a central line is shown together with the theoretical value of phase for the lens with focal length 333 mm. The result seems fairly good.

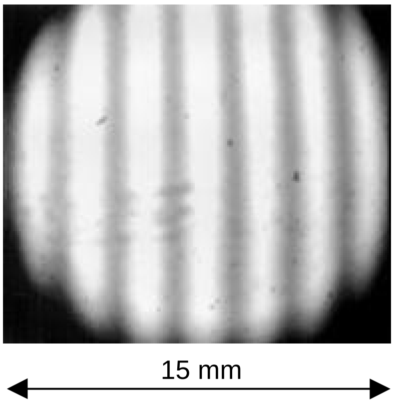

Figure 2. Fringe pattern for a lens with focal length 333 mm

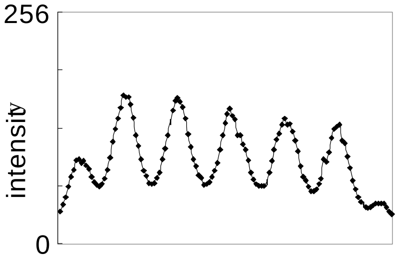

Figure 3. Intensity distribution Of along a horizontal line of a fringe pattern.

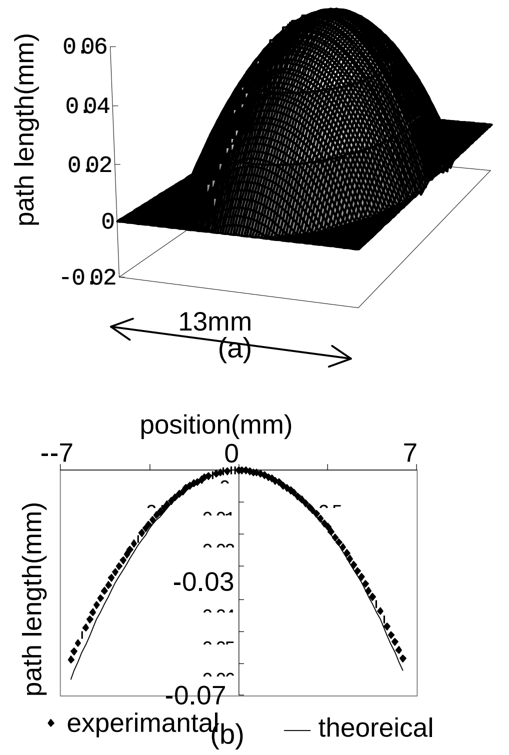

Figure 4. Experimental results for a spherical lens
(a) Two-dimensional phase distribution
(b) Phase distribution along a line

The present system can be modified to measure the profile of the reflecting surface. The modified system is shown in Fig. 5. In this system two gratings are used both to produce sheared beams and to recombine them. Phase shift is produced by moving one of the grating G_1. Because the grating G_1 diffracts one of the beams in the going way and the other beam in the returning way, phase shift is twice as much as the system shown in Figure 1.

The system was constructed with the same grating as Fig. 1. In order to translate the grating precisely we used a lever mechanism to reduce the movement of the micrometer. With this system we measured profile of a spherical mirror and a result similar to Fig. 4(b) is obtained. The discrepancy between the experimental and the theoretical value is smaller than 1 µm.

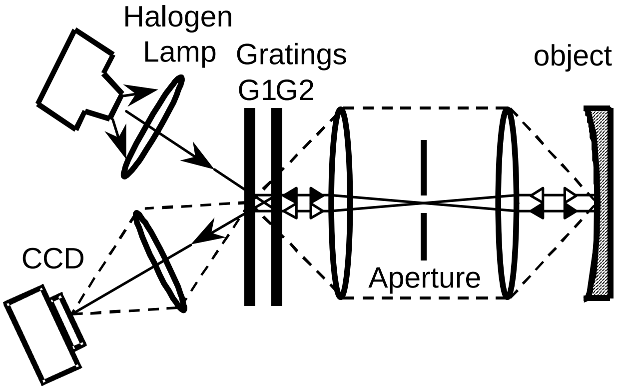

Figure 5. Shearing interferometer for a reflecting object

4.CONCLUSION

This paper proposed an achromatic shearing interferometer in which four gratings are used for making sheared beams and recombining them. Experiments are performed to measure phase distributions of a spherical lens and mirror. The resultant phase distributions agrees with theoretical values within a few microns.

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