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APPLICATIONS OF THE LATERAL SHEARING INTERFEROMETER IN
MEASUREMENT OF SYNCHROTRON RADIATION OPTICAL ELEMENTS*

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Introduction

Synchrotron radiation is of growing importance to a wide range of scientific disciplines. Consequently, greater effort is beginning to be devoted to the characterization of mirrors and other optical elements typically included in synchrotron radiation beamlines.¹

We describe here some applications of a device which we have found particularly convenient, both in the optical testing laboratory and for in-situ measurements. This device is the shearing or Murty interferometer.²

The principle of the Murty interferometer is comparatively simple. It can be used to measure optical elements in camera lenses, microscope objectives, projector lenses, etc., which have short focal lengths, while it is also suitable for measuring mirrors for monochromators, spectrographs and spectrometers which usually have large apertures and long focal lengths. The method of shearing interferometry is especially useful for mirrors having a large radius of curvature and large size as used in synchrotron radiation beamlines.

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This method is not only convenient, but also affords higher accuracy than most grazing incidence tests. In the present paper, the use of a single plate shearing interferometer for measuring the surface quality of several optical elements is reviewed and several results are given.

Principle of the Murty Interferometer

The principle arrangement of the shearing interferometer using a single plate is shown in Fig. 1. The parallel-sided plate used as the shearing element is placed in the path of the beam whose wavefront curvature it is desired to ascertain. The shearing plate reflects the wavefront from its front and back surfaces, producing two identical wavefronts with a lateral displacement. Interference fringes will occur in the region of overlap between the two wavefronts.

In Fig. 1 the plate is considered as strictly parallel. The wavefront direction of propagation is in the plane of the paper, and the incidence wave function ψ_1 , having unit amplitude, can be written as

$$\psi_1 = e^{i\theta_0(x,y)} \quad (1)$$

where θ_0 is the phase function describing the wavefront. The function ψ_1 , after reflecting from the front surface, is still the function ψ_1 , and after reflecting from the back surface becomes the function ψ_2 ,

$$\psi_2 = e^{i[\theta_0(x+S,y)]} \quad , \quad (2)$$

where S , the lateral shear distance, can be given by a simple geometric relation.

For a spherical wavefront,

$$\psi_1(x,y) = e^{i\alpha(x^2+y^2)} \quad , \quad (3)$$

where $\alpha = K/2R_L$, R_L = radius of curvature of the spherical wavefront, and $K = 2\pi/\lambda$.

The phase difference between ψ_1 and ψ_2 in the recording plane is,

$$\Delta\theta = \alpha(2Sx - S^2) \quad . \quad (4)$$

When $\Delta\theta = 2m\pi$ ($m = 0, 1, 2 \dots$), interference fringes in the region of overlap produce intensity maxima located at points x that satisfy,

$$\alpha(2Sx - S^2) = 2m\pi \quad . \quad (5)$$

Taking differentials in Eq. (5), we are led to,

$$\alpha \cdot S \, dx = \pi \, dm \quad . \quad (6)$$

Using $\alpha = K/2R_L$, Eq. (6) becomes,

$$\lambda \, dm = \frac{S}{R_L} \, dx \quad . \quad (7)$$

When the fringe order, dm , changes by one unit, the corresponding dx is the fringe spacing D and Eq. (7) can be changed to

$$R_L = \frac{SD}{\lambda} \quad . \quad (8)$$

It is seen from Eq. (8) that if S (the shear distance) and D (the fringe spacing) are known, then R_L , the radius of curvature of the wavefront, can be calculated.

In the foregoing, the plate was considered as strictly parallel. This requirement is in practice inconvenient because the fringe spacing becomes very large when the wavefront has small aberrations and the light is perfectly collimated. It is actually more convenient to have a small tilt between the two sheared beams in a direction perpendicular to the direction of lateral shear. This is easily achieved by making the plate slightly wedge-shaped. The experiments in the present paper were performed using such a wedged plate. When a wedged plate is used in the Murty interferometer, the incident beam collimation can be adjusted to planarity by obtaining horizontal straight fringes in the overlapping region of the sheared wavefronts on the reference screen. The interference fringes are inclined with respect to the direction of the shear when the collimation is imperfect.

The radius of curvature of the test wavefront at the recording plane is calculated from the following relation,³

$$R_L = \frac{SD}{\lambda \sin\theta} \quad , \quad (9)$$

where θ is the angle of rotation of the fringes with respect to the direction of shear.

The lateral shear distance S is given by,³

$$S = \frac{t \cdot \sin 2i}{(n^2 - \sin^2 i)^{1/2}}, \quad (10)$$

where i is the angle of incidence and n is the refractive index of the glass plate. For a plane incident wave, the radius of curvature of the mirror, r , is obtained from the following relation,

$$r = 2(R_L \pm L), \quad (11)$$

where L is the distance of the mirror from the recording plate via the shearing plate (+ sign is used for concave mirror, - for convex).

Reference 4 gives expressions for the sensitivity of the measurements to the radius of curvature.

Applications of the Shearing Interferometer on Measurements of the Synchrotron Radiation Optical Elements in NSLS

Because of the ease of use of the lateral shearing interferometer, it can be used to test many of the optical elements used in synchrotron radiation beamlines. If suitable windows are available, in-situ measurements can be made relatively straightforwardly. In such cases the effects of radiation heating on the optical figure of the elements can be studied.⁴

The layout of the interferometer used in the experiments described in the present work is shown in Fig. 2.

The parameters for the glass plate used in the test are:

refraction index	$n = 1.515$
thickness	$t = 12 \text{ mm}$
diameter	$w = 100 \text{ mm}$

Figures 3 and 4 show two interferograms taken from paraboloidal mirror P-5 used in the grazing incidence Plane Grating Monochromator (PGM) at the NSLS and from the focussing mirror to be used in Beamline 3 at the Beijing e-p collider (BEPC),⁵ respectively. It is seen from interferogram 3 that mirror P-5 has obvious surface ripples of wavelengths around 1 mm. The cylindrical mirror BL-3 has uniform interference fringes, with no evidence of short-range ripples.

A situation which often occurs in synchrotron radiation optics is that in which the numerical aperture of the optical element is so small that at visible light wavelengths they are severely diffraction limited. This was the case for a spherical crystal surface produced by elastically deforming a plane parallel plate. This element was used by one of us⁶ to produce well-focussed highly monochromatic hard x-rays by near-normal incidence Bragg reflection. Testing of the quality of the focal spot could not be performed using visible light since the diffraction limited spot size under the appropriate conditions was around 1 mm. The Murty interferometer allowed us very quickly to diagnose various problems with the elastic deformation fixture and correct them, and to make a good initial adjustment to the curvature radius, hence minimizing the more difficult task of adjustment in-situ using x-rays. Figure 5 shows an interferogram produced by a 0.3 mm thick plate in its natural, unstrained

state. It can easily be seen that it is not flat, and is totally unsuitable for producing the large radii (17.5 m) that were needed. Figure 6 shows a similar image, but from a 1 mm thick wafer. It is significantly better than the thinner device, although still not perfect. Figure 7 shows the result of using non-planar bending rings in the spherical-bending fixture. Finally, Fig. 8 shows the final figure obtained for the correct curvature radius, a figure which proved satisfactory.

Figures 9 and 10 are interferograms taken from mirror P-5 inside a vacuum oven at different temperatures using the shearing interferometer. Figure 9 was obtained when the mirror was heated up to 98°C after 3 hours when the temperature inside the oven balanced. The interferogram (Fig. 10) was obtained at room temperature. We can easily draw a conclusion from the comparison between these two interferograms that when the temperature inside the vacuum oven is in a steady state, deformation of the mirror is too small to see because there is no fringe change. Both Figs. (9) and (10) were taken in the same experimental conditions; the incidence angle was 30°. The distance from the tested mirror to the recording plane was $L = 78$ cm.

Summary

The tests demonstrated above have shown the usefulness of the shearing interferometer for assessing the quality of the surface of the mirrors and other optical elements used in the SR beamline. The test is easy to set up and is convenient to perform using readily available He-Ne lasers.

Although in this work only qualitative conclusions are drawn from the interferograms, quantitative analysis is possible.⁴ This technique is expected to find more usefulness in the SR optical laboratory.

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Fig. 1. Schematic diagram of principle of the shearing interferometer.

Fig. 2. Schematic diagram of Murty Interferometer to measure the radius of curvature.

1. HeNe laser.
2. Microscope objective.
3. Pinhole.
4. Collimating lens.
5. Reference screen.
6. Test recording plane.
7. Wedged shearing plate.
8. Mirror under test.

Fig. 3. Lateral shearing interferogram for the paraboloidal mirror P-5 used in the grazing incidence PGM at the NSLS.

Fig. 4. Lateral shearing interferogram for the mirror used in Beamline-3 at BEPC.

Fig. 5. Lateral interferogram for the crystal plate with thickness 0.3 mm with no bending force applied.

Fig. 6. Lateral shearing interferogram for the crystal plate with thickness 1 mm with no bending force applied.

Fig. 7. Non-uniform bending produced when the concentric cylinders used to produce the bending forces were inadequately lapped.

Fig. 8. Interferogram of 1 mm thick wafer bent to radius of 17.5 meters using properly lapped force rings.

Fig. 9. Lateral interferogram for the mirror P-5 inside vacuum oven at room temperature.

Fig. 10. Lateral interferogram for the mirror P-5 inside vacuum oven at 98°C.