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Improved collimation testing using Talbot interferometry

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Several schemes for checking collimation of a light beam based on the self-imaging (Talbot effect) combined with the moire technique have been described.[1-4] When a grating is illuminated by a collimated beam of monochromatic light, exact self-images of the grating are formed at certain well-defined planes perpendicular to the direction of the beam. The moire pattern is observed by placing an identical second grating at one of these planes. In the event of the illuminating beam being noncollimated, the spatial frequency of the self-image is different from that of the grating itself. This change in frequency is detected by a change in the moire pattern. This is the basic principle of collimation testing by this method. We present a variation of this technique which has a twofold increase in the sensitivity and does not require a separate reference.

A grating illuminated by a collimated beam produces self-images at several distances from the grating given by
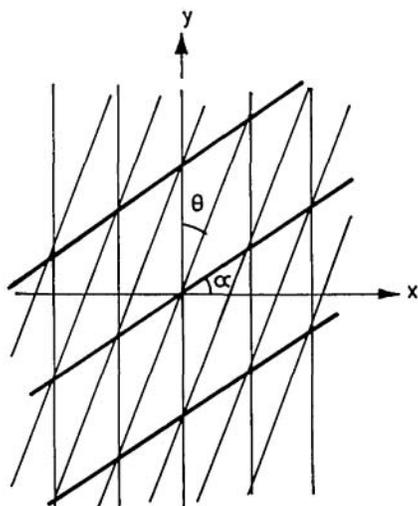
$$Z_m = m/\lambda\mu^2, \qquad (1)$$

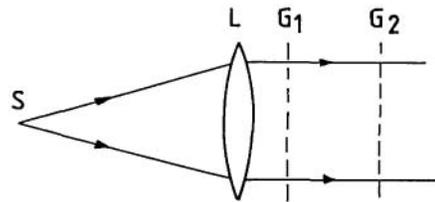Fig. 1. Moire fringes formed by two gratings of unequal period.

Fig. 2. Experimental arrangement for collimation testing by Talbot interferometry.

where μ is the spatial frequency of the grating, m is an integer, and λ is the wavelength of light.

When the grating is illuminated by a spherical wave the change in frequency $\Delta\mu$ of its self-image is given by

$$\frac{\Delta\mu}{\mu} = \frac{Z_m}{R}, \qquad (2)$$

where R is the radius of the wavefront. If the spherical wavefront is due to defocusing Δf of a collimating lens, R is given by

$$R = \frac{f^2}{\Delta f}, \qquad (3)$$

where f is the focal length of the collimating lens.

Figure 1 shows two gratings of frequencies μ_1 and μ_2 superimposed with their lines making an angle θ with each other. The lines of one of the gratings are assumed to be parallel to the y axis. Moire fringes are generated which are inclined at an angle α with the x axis given by

$$\tan\alpha = \frac{\mu_2\cos\theta - \mu_1}{\mu_2\sin\theta}. \qquad (4)$$

When $\mu_1 = \mu_2$, i.e., the gratings are identical,

$$\tan\alpha = -\tan\theta/2. \qquad (5)$$

Equation (5) indicates that the moire fringes are perpendicular to the bisector of the angle between the lines of the two gratings. If the lines of the two gratings are oriented at equal but opposite angles with respect to the y axis, horizontal (parallel to the x axis) moire fringes are formed.

Figure 2 shows the basic arrangement to generate moire fringes using Talbot interferometry. A point source S placed at the focus of a lens L generates the collimated beam to be tested. G_1 and G_2 are two identical gratings. G_2 is placed in the plane of the self-image of G_1. In practice the lines of the gratings make small but equal angles on either side of the vertical so that the moire fringes are horizontal with the collimated illuminating beam. However, if the illuminating beam is spherical, the spatial frequency of the self-image of G_1 varies according to Eq. (2), and the moire fringes rotate. In other words, horizontal moire fringes are indicative of the collimation of the illuminating beam. Any rotation from this reference orientation is a test for departure from collimation.

It is rather difficult to establish this reference orientation of the moire fringes, as it requires a precise rotation mechanism for gratings. We also need to establish vertical and horizontal (two orthogonal) directions.

This difficulty can be avoided in a variation of the technique proposed here. The gratings G_1 and G_2 are divided in two parts in the middle with the lines slightly inclined in opposite directions as shown in Fig. 3. For simplicity we assume that (1) the lines in the two parts are inclined at equal angles with the central reference line AB and (2) the frequen-
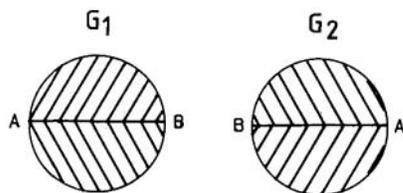
Fig. 3. Grating structure for use in the proposed technique of the collimation test.
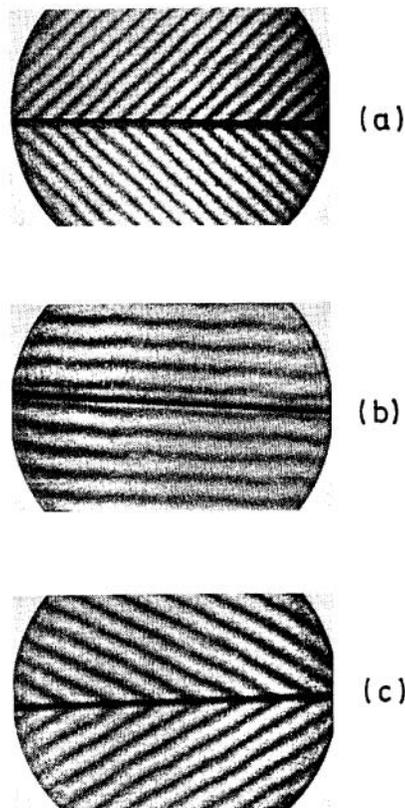

Fig. 4. Moire fringes obtained with the modified gratings used for collimation test. Light source (a) inside the focus, (b) at the focus, and (c) outside the focus.

cies of the gratings in the two parts are equal. In the grating G_2, the orientation of lines is opposite that of G_1. When two such gratings (G_1 and G_2) are superimposed so that the grating lines intersect at the same angle in the two halves (this happens when the central line AB of the two gratings is coincident or parallel), equally spaced moire fringes are formed in the two halves.

When these gratings are placed in the collimation test arrangement shown in Fig. 2, parallel equally spaced moire fringes are formed as above when the collimated beam is incident on G_1. However, if the incident beam is noncollimated, the spatial frequency of the self-image of G_1 varies by the same amount in both halves, resulting in rotation of the moire fringes, which interestingly is in the opposite direction in the two halves. Thus the lack of collimation is detected with double the sensitivity compared to the previous technique. Figures 4(a)–(c) show the moire fringes obtained with the point source inside, at, and outside the focus of the collimating lens, respectively.

If the central line AB of the two superposed gratings is inclined, the grating lines do not intersect at the same angle in the two halves, giving moire fringes of different spacing in the two halves. Their orientation also changes. However, the fringes are still parallel to each other in the whole field when the illuminating beam is collimated.

In fact, it is not necessary for the frequency and inclination of the lines of gratings in the two halves to be equal, as assumed earlier. It can be shown that with such gratings, the moire fringes are parallel to each other in the whole field for collimated beam illumination. The only condition to be satisfied is that G_1 and G_2 are identical, which is easily obtained if G_2 is obtained as a copy of G_1. Thus parallelism of moire fringes provides a reference field as a test for collimation in this method. No precise reference direction or components for setting of the gratings is required. We have here a self-referencing technique.

Summarizing: we have described a technique for collimation testing which provides its own reference field. Also, the detection sensitivity is doubled.

The linear grating from which G_1 and G_2 were made was supplied by CSIO, Chandigarh.

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