

Optical configuration for measurement in speckle interferometry

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Received July 26, 1996

An optical configuration for measurement of in-plane displacement and for contouring is reported. In this method an object point is viewed symmetrically with respect to surface normal and combined coherently at the image plane of the imaging system. Because the beams are combined by small apertures at the image plane, decorrelation sets in rather slowly. Owing to low decorrelation, fringes have been obtained for large in-plane deformations and large angular tilts. The method is simple to implement, and its sensitivity can be varied over a wide range. The configuration, therefore, extends the range of measurement. © 1996 Optical Society of America

Leendertz¹ suggested an optical configuration that is sensitive to in-plane displacement and fully compensates for the out-of-plane displacement. The main drawbacks of the Leendertz method are very low contrast of speckle fringes and rapid decorrelation that restrict the range of measurement. A method developed by Duffy^{2,3} gives good contrast fringes but is less efficient from the standpoint of light management and is of much lower sensitivity than the method of Leendertz. Essentially all existing methods of in-plane measurement can be grouped into two categories: those with dual directions of illumination and a single direction of observation (Leendertz) and those with a single direction of illumination and dual directions of observation (Duffy).^{4,5}

The proposed optical configuration also uses a single direction of illumination and dual directions of observation. Unlike for Duffy's method, the sensitivity is very large and is equal to that of the Leendertz method, but the decorrelation sets in slowly as the beams through small apertures are combined coherently at the image plane. The method can therefore be considered equivalent to Duffy's but with sensitivity equal to that of Leendertz and with very slow decorrelation. Experimental results from a cantilever beam for in-plane displacement and a light bulb for contouring are presented.

Figure 1 shows a schematic of the optical arrangement. The diffuse object is illuminated normally with a collimated beam from a 25-mW He-Ne laser. It is viewed along directions θ and $-\theta$ with respect to the local normal by means of two pairs of mirrors (M_1, M_3) and (M_2, M_4). In the experimental setup the angle between mirrors M_3 and M_4 is fixed (90°), and mirrors M_1 and M_2 are used for alignment of images. The mirrors are aligned such that the two scattered fields from the object through mirrors (M_1, M_3) and (M_2, M_4) combine coherently at the image plane. A two-aperture mask is placed in front of the lens, and a gratinglike structure within each speckle is thus generated at the image plane. The aperture mask, however, is not necessary, but aperturing improves the contrast of the fringes in

the interferogram.⁶ An exposure is made on the photographic plate. The object is loaded, and another exposure is made on the same plate. The total recorded irradiance I at the recording plane can be expressed as

$$I = 2 \left[I_1 + I_2 + 2\sqrt{I_1 I_2} \times \cos \left(\varphi_{12} + 2\pi\mu x + \frac{\delta_{12}}{2} \right) \cos \frac{\delta_{12}}{2} \right], \quad (1)$$

where I_1 and I_2 are the irradiances of the two scattered fields, φ_{12} is the random phase difference, δ_{12} is the phase difference that is due to deformation, and μ is the grating frequency formed by two apertures.

After processing, the double-exposure record (specklegram) is whole-field filtered.⁵ Three halos are formed at the Fourier transform plane; filtering through one of the first-order halos results in an interferogram. The condition for the bright-fringe formation corresponds to

$$\delta_{12} = (\mathbf{K}_1 - \mathbf{K}_2) \cdot \mathbf{L} = 2m\pi. \quad (2)$$

Because the sensitivity vector $(\mathbf{K}_1 - \mathbf{K}_2)$ lies in the plane of the object, only the in-plane displacement component lying in the plane of the figure ($x-z$ plane)

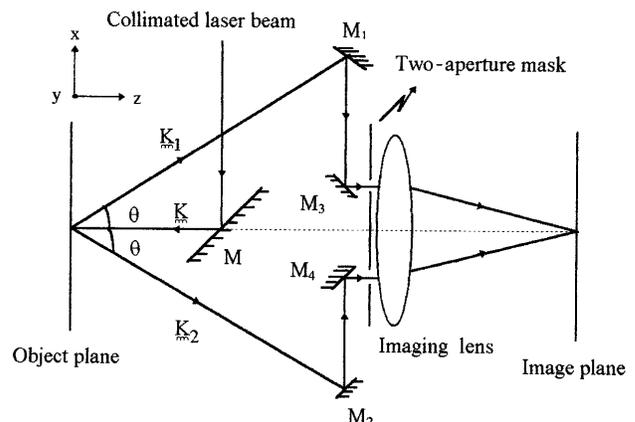


Fig. 1. Schematic of the experimental arrangement.

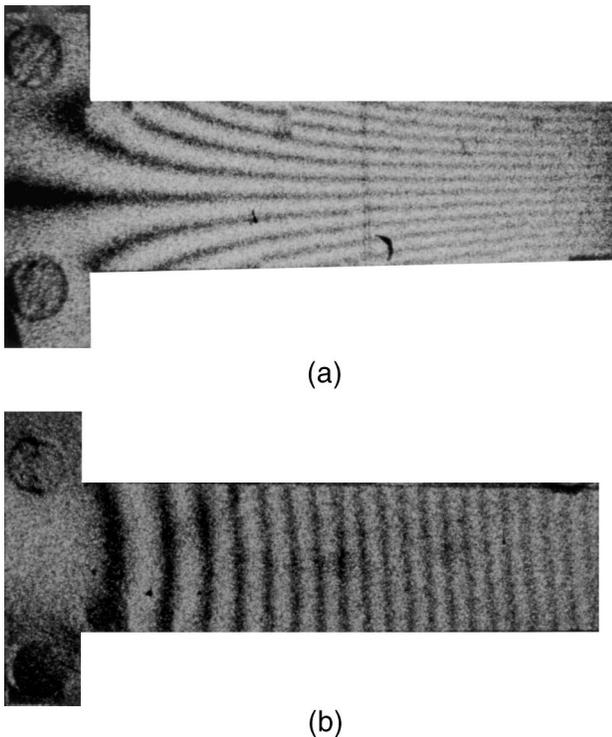


Fig. 2. Experimental results from a cantilevered beam of length $80 \text{ mm} \times 30 \text{ mm} \times 5 \text{ mm}$. The observation angle θ is $\sim 25^\circ$. (a) u -family and (b) v -family fringe patterns were photographed from one of the first-order diffraction halos by use of Fourier filtering.

is sensed. The vector $\mathbf{L}(u, v, w)$ is the deformation vector at any point on the object with component $\mathbf{L} = u\hat{i} + v\hat{j} + w\hat{k}$.

Thus Eq. (2) can be rewritten as

$$2u \sin \theta = m\lambda, \quad (3)$$

where λ is the wavelength of laser light used for recording and m is an integer. The fringes are loci of constant u , and the separation between the fringes corresponds to

$$\Delta u = \frac{\lambda}{2 \sin \theta}. \quad (4)$$

The sensitivity is thus governed by angle 2θ between the observation directions, and one can alter it by shifting mirrors M_1 and M_2 appropriately. The v family of fringes is obtained either by rotation of the object about the normal by 90° or by rotation of the observation system by 90° about the y axis.

Figures 2(a) and 2(b) show the u and v families of fringes obtained from a cantilevered beam subjected to transverse load to produce an in-plane displacement at the free end. The observation angle θ is $\sim 25^\circ$. The fringes are nearly of holographic quality.

This arrangement can also be used for contouring. The object is rotated by a small angle $\Delta\phi$ about the y axis between the exposures.⁵ The contour interval Δz is given by

$$\Delta z = \frac{\lambda}{2 \sin \theta \Delta\phi}. \quad (5)$$

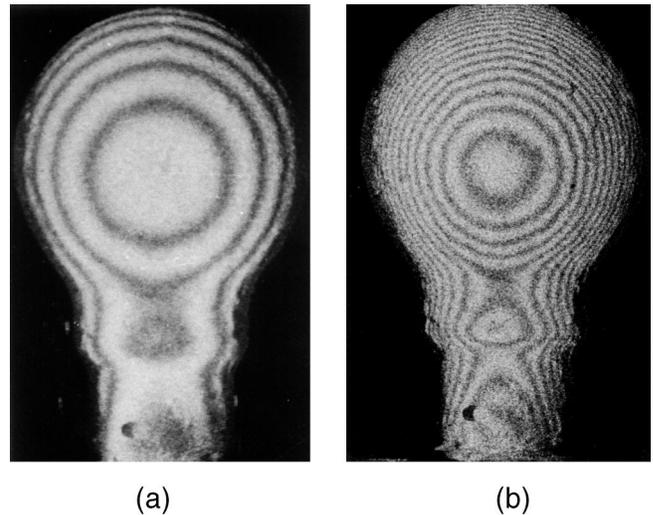


Fig. 3. Contour fringes of a light bulb filtered by one of the first-order diffraction halos. The contour interval Δz is (a) 1.69 mm and (b) 0.564 mm .

Figures 3(a) and 3(b) show interferograms depicting contour fringes on a domestic light bulb. Again, one may notice that the decorrelation is very low, and contour fringes with a very small contour interval are visible [Fig. 3(b)]. This is in contrast to our earlier method⁷ in which the fringe contrast falls off very rapidly.

We have proposed an optical configuration that relies on normal illumination and dual directions of observation. Because the two beams through two small apertures are combined coherently at the image plane, decorrelation sets in very slowly. In brief, an optical configuration with sensitivity equal to that of the Leendertz configuration and a larger range of measurement owing to lower decorrelation has been proposed, and experimental results for in-plane displacement of a cantilever and contour fringes on a domestic bulb were presented.

The authors are thankful to the referee for suggesting improvements in the scientific content of this Letter.

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