Optica Applicata, Vol. XV, No. 3, 1985

Letter to the Editor

A possibility of increasing the sensitivity of defocused speckle photography

Jordanka Georgieva, Maria Dentcheva

Higher Institute of Civil Engineering, Department of Physics, Sofia, Bulgaria.

The double exposure speckle photography has proved to be a simple and convenient method for measurements of displacements, surface roughness, vibration amplitude, etc. [1]. Being a noncontacting method and involving the whole field the method is applicable to various objects and materials.

For measurement of local tilt values the technique proposed in [2] is usually used. The object is illuminated with divergent laser beam and photographed twice (before and after tilting) on the same emulsion. The imaging camera is not focused on the tilted surface but on a parallel plane disposed at a distance A in front of the object or behind it. When the surface is tilted at an angle Ψ and the illumination and the recording are almost perpendicular, the speckles in the image plane will move at a distance

$$D = 2\Psi MA \tag{1}$$

where M is the magnification factor. The local tilt values may be obtained either by point-by-point scanning with unexpanded laser beam or by whole field filtering, as in the case of in-plane speckle photography. The geometry conditions can be chosen so that the tilt obtained is independent of the lateral displacement [3]. When the object, imaging camera and the illuminating laser source are located arbitrarily, the optical setup is sensitive to in-plane displacements of the object. This fact may be used for decreasing the lower limit of measurable tilt values when pure tilt occurs in a way similar to that in focused speckle photography [4] due to camera translation at a distance perpendicular to its optical axis.

Let, as shown in Figure 1, the camera be focused on plane A. The speckle displacement vector in the image plane OXY is

$$\boldsymbol{D} = \boldsymbol{D}_{\Psi}+\boldsymbol{D}_0 \tag{2}$$

where $\boldsymbol{D}_{\Psi}$ is due to the tilt and $\boldsymbol{D}_0$ to the camera translation $\boldsymbol{d}_0$ introduced between the two exposures. The angle between $\boldsymbol{D}_{\Psi}$ and $\boldsymbol{D}_0$ is Θ. For simplicity, the axis OX is oriented along $\boldsymbol{D}_0$. A fixed reference object, placed in the focused plane, is imaged simultaneously with the tilted surface on the same frame. When the doubly exposed specklegram is scanned with an unexpanded laser beam, two systems of Young's fringes will appear. The fringes from the inves-

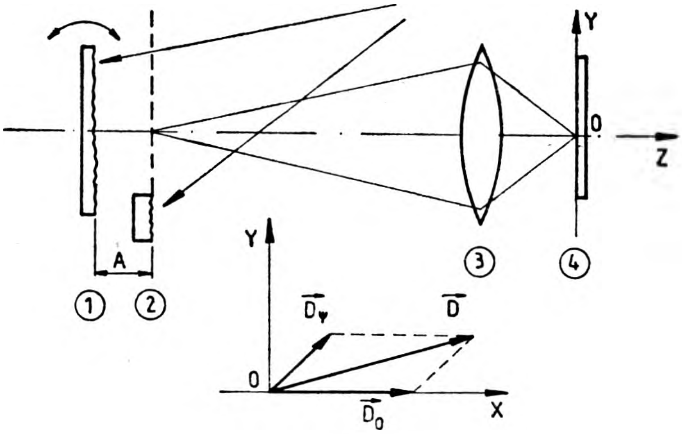

Fig. 1. Setup for increasing the sensitivity of defocused speckle photography. 1 — investigated, object, 2 — fixed reference object, 3 — camera lens, 4 — photoplate

tigated object will have a spacing a and an inclination angle α to the vertical direction

$$a = \frac{\lambda L}{M|\boldsymbol{D}_\Psi|}, \qquad \alpha = \text{arc tan}\,\frac{D_{\Psi_y}}{D_0 + D_{\Psi_x}}. \tag{3}$$

D_{Ψ_x} and D_{Ψ_y} in (3) are the components of D_Ψ, λ is the wavelength used, and L — the distance between the specklegram and the screen.

The second fringe pattern from the reference object will have a spacing a_0 and an inclination angle α_0:

$$a_0 = \frac{\lambda L}{M|\boldsymbol{D}_0|}, \qquad \alpha_0 = 0. \tag{4}$$

By measuring distances a_m (between m fringes from the investigated object) and a_n (between n fringes from the reference object) and the inclination α, the components Ψ_x and Ψ_y are obtained as follows:

$$\begin{aligned} \Psi_x &= \frac{\lambda L}{2AM}\left(\frac{m\cos\alpha}{a_m} - \frac{n}{a_{0n}}\right), \\ \Psi_y &= \frac{\lambda L}{2AM}\,\frac{m\sin\alpha}{a_m}. \end{aligned} \tag{5}$$

Two special cases are of interest:

i) $\boldsymbol{D}_0$ and $\boldsymbol{D}_\Psi$ are collinear ($\Theta = 0$)

$$\Psi_x = \frac{\lambda L}{2AM}\left(\frac{m}{a_m} - \frac{n}{a_{0n}}\right), \quad \Psi_y = 0, \tag{6}$$

ii) $\boldsymbol{D}_0$ and $\boldsymbol{D}_\Psi$ are perpendicular ($\Theta = \pi/2$)

$$\Psi_x = 0, \quad \Psi_y = \frac{\lambda L}{2MA}\sqrt{\frac{m^2}{a_m^2} - \frac{n^2}{a_{0n}^2}} \quad \text{or} \quad \Psi_y \frac{d_0}{2A\tan\alpha}. \tag{7}$$

In the second case Ψ_y may be determined either from the spacings a_m and a_{0n}, or from the inclination angle α only. In this way the translation of additional camera permits us to increase the sensitivity of speckle photography to tilt measurements, thus to measure smaller tilts. d_0 should be chosen so as to obtain well located fringes. It is possible, moreover, to determine the sign of the object tilt, which cannot be done when the traditional technique is used.

The inaccuracy of the proposed method for tilt measurements is determined from the expressions:

$$\frac{\Delta\Psi}{\Psi} = \frac{\Delta\lambda}{\lambda} + \frac{\Delta L}{L} + \frac{\Delta M}{M} + \frac{\Delta A}{A} + \frac{(m^2a_{0m}^2 + n^2a_m^2)\,\Delta a}{a_m a_{0n}(ma_{0n} - na_m)}, \tag{8}$$

when $\boldsymbol{D}_0$ and $\boldsymbol{D}_\Psi$ are collinear, and

$$\begin{aligned} \frac{\Delta\Psi}{\Psi} &= \frac{\Delta\lambda}{\lambda} + \frac{\Delta L}{L} + \frac{\Delta M}{M} + \frac{\Delta A}{A} + \frac{(m^2a_{0n}^2 - mna_{0n}a_m + n^2a_m^2)\,\Delta a}{a_m a_{0n}(ma_{0n} - na_m)}, \\ \frac{\Delta\Psi}{\Psi} &= \frac{\Delta d_0}{d_0} + \frac{\Delta A}{A} - \frac{2\Delta a}{\sin 2a}, \end{aligned} \tag{9}$$

when $\boldsymbol{D}_0$ and $\boldsymbol{D}_\Psi$ are perpendicular.

A series of experiments were performed to prove the feasibility of the technique.

The experimental setup shown in Fig. 1 was constructed so that independent measurements of tilt values could not be performed. A helium neon laser type HNA–50 and a photocamera Practica with a film ORWO MA8 were used. The camera was mounted on a stage which allowed translations perpendicularly to its optical axis in a strong horizontal direction. Between the exposures the object was tilted, and the camera translated at a distance d_0.

Figure 2 shows the examples of fringe patterns obtained through point-by-point scanning: from the object without camera translation (a), from the reference object (b), and from the object with camera translation (c). Some numerical results are presented in the Table The values measured directly and those calculated by the described procedure are in good agreement.

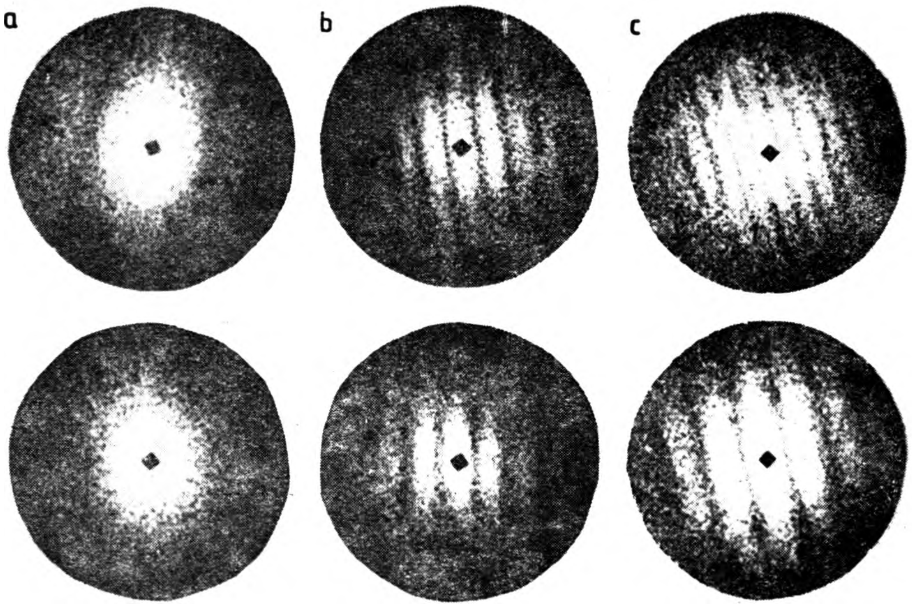

Fig. 2. Fringe pattern obtained from the object without camera translation (a), from the reference object (b), and from the object with camera translation (c)

Ψ, 10^{-4} [rad]	δx [μm]	Ψ_0, 10^{-4} [rad]
0.91	174	0.87
0.66	170	0.70
4.90	290	4.60
3.68	143	3.48
3.64	300	3.64
1.51	350	1.52

(Ψ — tilt values measured through the proposed technique, δx — camera translation, Ψ_0 — directly measured tilt values)

The proposed method was also applied to study the deformed state of a metal ($10 \times 0.3 \times 50$ cm) plate under concentrated end load. The loading diagram is shown in Fig. 3a. The maximum deflection W_0 was given and the tilt values $W'(x)$ were measured. By applying camera translation the tilt was determined over the whole surface of the specimen, while with the traditional technique it could be done only for a small part of the surface. A comparison between the experimental results and the theoretical calculations for $W_0 = 320$ μm is presented in Fig. 3b. The accuracy of measurements without camera translation is worse because of bad fringe quality near the lower limit of measurable tilts.

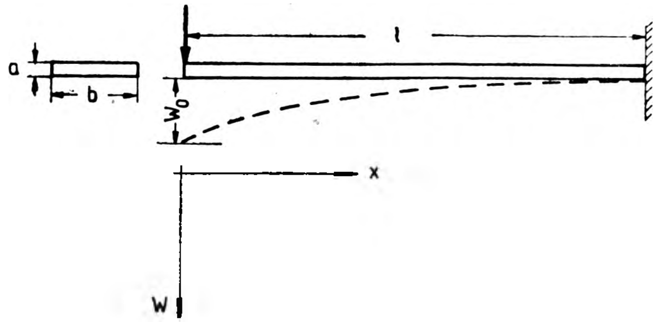

Fig. 3a. Loading diagram of a metal plate

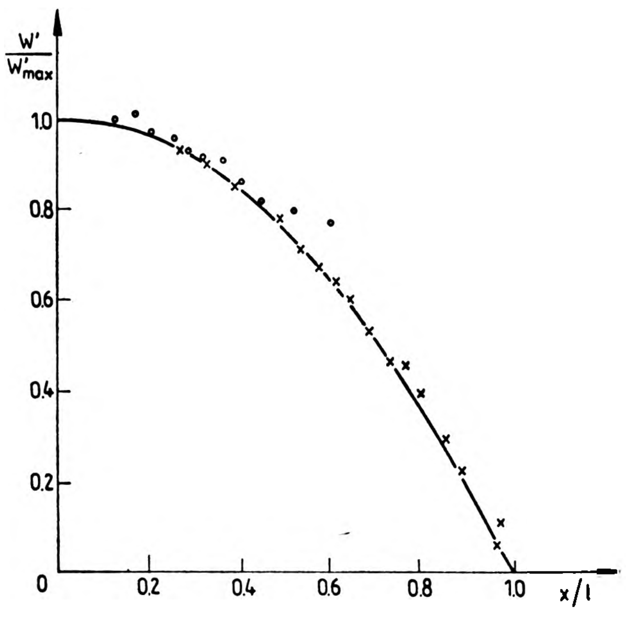

Fig. 3b. Comparison of theoretical and experimental results (—— theoretical, × experimental with camera translation, ○ experimental without camera translation)

Thus, the proposed procedure gives us the possibility of increasing the sensitivity of defocused speckle photography and allows to determine the unknown direction of the tilt. The sensitivity may be varied also by changing the distance between the object and the focused plane, but it cannot be done in a wide range, especially when the object is not uniformly tilted, because then the visibility of the fringes is worse. It should be noted that the described procedure, being free of this disadvantage, may be used for studying the deformed state of different materials and objects.

References

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Received January 11, 1985