

HOLOGRAPHY

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Holographic variable-sensitivity lateral shear interferometry for studying rapid processes

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***Abstract*. A new method for simultaneous recording holograms with different lateral shears is proposed and realised. The method allows one to vary the measurement sensitivity in a broad range during the optical processing of holograms. The results of the experimental test of the method are presented which demonstrate the possibility of its applications, in particular, for studying rapid processes.**

Keywords: *holographic interferometry, lateral shear, interference pattern, measurement sensitivity*.

1. Introduction

In interferometric studies the problem of incompatibility between the sensitivity of the method and the range of variations in the measured parameter of an object often arises. In the case of two-beam holographic interferometry with the reference wave, this problem is solved, as a rule, by using multiwave recording of holograms [1 – 4]. In the case of many simultaneously recorded holograms or interferograms recorded by radiation at different wavelengths, the problem of matching the sensitivity of interferometric measurements with the range of variations in the measured parameter of the object under study is considerably simplified [5].

The lateral shear interferometry is simpler in practice than the two-beam interferometry with the reference wave and has a comparable measurement accuracy [6, 7].

One of the features of the lateral shear interferometry in the case of small shears is the directly proportional dependence of the sensitivity of this method on the shear value [8]. This circumstance allows one to vary the sensitivity of the interference method according to the value of the measured parameter both at the stage of recording shear interferograms and their reconstruction from holograms of the object under study [9, 10].

In the study of rapid processes, when the range of variations in the measured parameter is uncertain, it is desirable to obtain simultaneously several interferograms with different lateral shears, which represent the measured parameter with different sensitivities.

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In this paper, we consider a new method for simultaneous recording holograms with different lateral shears. This method allows us to obtain interference patterns during optical processing which represent the parameter of the object under study with the measurement sensitivity variable in a broad range.

2. Recording shear holograms

Figure 1 shows the optical scheme of the setup for simultaneous recording of holograms with different lateral shears. Radiation from LGN-212 laser (*1*) was collimated with telescopic system (*2, 3*) to a light beam corresponding to the size of object (*4*). Telescopic system (*5, 6*) reduced the diameter of the object beam. At the output of lateral shear interferometer (*7*) in the region optically conjugated with object (*4*), along the path of the object beam (axis z), n photographic plates (*8*) were placed in series for simultaneous recording of holograms with different lateral shears.

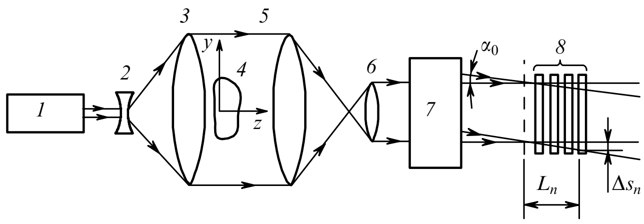

Figure 1. Optical scheme of the setup for recording shear holograms: (*1*) LGN-212 laser; (*2, 3* and *5, 6*) telescopic optical systems; (*4*) object; (*5*) lateral shear interferometer; (*8*) recording planes of shear holograms.

Upon recording lateral shear holograms, the object plane with a plane wave front deformed by object (*4*) is divided in amplitude into two waves in lateral shear interferometer (*7*). Let us assume that the first wave propagates along the z axis. Then, its complex amplitude can be written in the form

$$A_0(x, y) = a_1 \exp[\mathrm{i}\varphi([x, y)], \tag{1}$$

where a_1 is the real amplitude and $\varphi(x, y)$ are phase shifts caused by object (*4*). The second wave propagates at an angle of α_0 to the z axis, for example, in the yz plane. In this case, the complex amplitude of the second wave in the planes of photographic plates can be represented, according to (1) and Fig. 1, as

$$A_1(x,y) = a_1 \exp\{i[2\pi\eta y + \varphi(x, y + \Delta s_1)]\},$$

$$A_2(x,y) = a_1 \exp\{i[2\pi\eta y + \varphi(x, y + \Delta s_2)]\}, \tag{2}$$

....

$$A_n(x,y) = a_1 \exp\{i[2\pi\eta y + \varphi(x, y + \Delta s_n)]\},$$

where $\eta = \sin(\alpha_0)/\lambda$; λ is the wavelength of light source (*1*); Δs_1, Δs_2, ..., and Δs_n are the lateral shears of the wave front of the second light beam with respect to the first one. The lateral shears of the wave fronts of the second light beam with respect to the first one in the planes of photographic planes (*8*) are determined by the holographic angle α_0 and distances from the plane of exact coincidence of the first and second waves (dashed straight line in Fig. 1) to the photoemulsion layer of photographic plates. These parameters are shown in Fig. 1 for the nth photographic plate, for which

$$\Delta s_n = \frac{L_n \tan \alpha_0}{V}, \tag{3}$$

where V is the magnification of the telescopic system formed by objectives (*5, 6*).

Shear holograms are recorded on photographic plates upon interference of the first and second waves. The phase shift for the nth hologram will be determined by the difference $\varphi(x, y + \Delta s_n) - \varphi(x, y)$. If the value of Δs_n determined from (3) is much smaller than the size of the inhomogeneity under study, this difference can be replaced by $\Delta s_n\, \partial\varphi(x,y)/\partial y$. Therefore, after chemical processing the amplitude transmissions of shear holograms can be represented in the form [11]

$$\tau_1(x,y) = \left\{1 + \cos\left[\frac{2\pi y}{T} + \Delta s_1 \frac{\partial\varphi(x,y)}{\partial y}\right]\right\}^{-\gamma/2},$$

$$\tau_2(x,y) = \left\{1 + \cos\left[\frac{2\pi y}{T} + \Delta s_2 \frac{\partial\varphi(x,y)}{\partial y}\right]\right\}^{-\gamma/2}, \tag{4}$$

....

$$\tau_n(x,y) = \left\{1 + \cos\left[\frac{2\pi y}{T} + \Delta s_n \frac{\partial\varphi(x,y)}{\partial y}\right]\right\}^{-\gamma/2},$$

where T is the period of carrier fringes of the hologram and γ is the contrast coefficient of photoemulsion.

The sensitivity of measuring $\partial\varphi(x,y)/\partial y$ in holograms recorded in this way is different because the coefficients Δs_1, Δs_2, ..., Δs_n determined by expression (3) are different.

3. Production of interference patterns

Interference patterns with variable measurement sensitivity are obtained by using a scheme for optical processing single holograms by two coherent light beams (Fig. 2). Such a scheme was earlier used to obtain interference patterns and enhance the sensitivity of interference measurements upon optical processing holographic phase objects [12], photographs of projected fringes [13], images of defocused gratings [14], photographs of objects with a periodic surface texture [15], and holograms written upon a small lateral shear of the wave fronts [16].

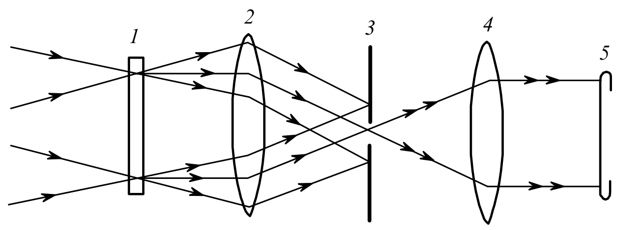

Figure 2. Scheme for optical processing shear holograms: (*1*) shear hologram; (*2, 4*) objectives; (*3*) aperture; (*5*) observation plane of the interference pattern.

One of the shear holograms is placed in position (*1*) (Fig. 2) and is illuminated by two coherent light beams with plane wave fronts so that to reconstruct normally to the hologram the waves diffracted to the lth and mth orders, which are separated in the specified focal plane of objective (*2*) with the help of aperture (*3*). In this case, the interference pattern of the type

$$I_n(x,y) \sim 1 + \frac{2a_l a_m}{a_l^2 + a_m^2} \cos\left[2\pi\left(\frac{x}{P_x} + \frac{y}{P_y}\right) + (l+m)\Delta s_n \frac{\partial\varphi(x,y)}{\partial y}\right], \tag{5}$$

is formed in plane (*5*), which is optically conjugated with shear hologram plane (*1*) by objectives (*2*) and (*4*), where a_l and a_m are the real amplitudes of the waves diffracted into the lth and mth orders ($l, m = 0, \pm1, \pm2, ...$). This interference pattern with fringes, whose width and orientation are determined by parameters P_x and P_y, represents the behaviour of the first derivative from variations in the phase of the object wave caused by the object under study with the sensitivity coefficient

$$K = [(l+m)\Delta s_n]. \tag{6}$$

If $P_x \to \infty$ and $P_y \to \infty$ the interference pattern in infinitely broadened fringes is observed in the region unperturbed by the object. If $P_x \to \infty$ and the value of P_y is finite and smaller than the width of the object beam, we have the interference pattern in horizontal (parallel to the x axis) fringes. If $P_y \to \infty$ and P_x is finite and smaller than the width of the object beam, the interference pattern is observed in vertical (parallel to the y axis) fringes. The values of P_x and P_y determining the shape of interference fringes can be varied by changing the angle between the light beams illuminating shear hologram (*1*) (Fig. 2).

It follows from expression (5) that the measurement sensitivity in the interference pattern is determined by the choice of the corresponding shear hologram (by the parameters Δs_1, Δs_2, ..., Δs_n) and by the selected diffraction orders (by integers l, m and their signs). It is obvious that the sensitivity coefficient will be minimal ($K_{\min} = \Delta s_1$) upon optical processing of the first shear hologram when the waves diffracted to the zeroth and first orders are selected. Its maximum value ($K_{\max} = 2l_{\max}\Delta s_n$) is achieved upon optical processing of the last (nth) shear hologram when the waves diffracted to the maximally remote complex-conjugate $l_{\max}$ diffraction orders are selected. The maximum values of the diffraction orders are limited in practice due to the decrease in the diffraction efficiency and increase in the noise with increasing the order number.

Thus, by selecting for optical processing the corresponding shear hologram from a series of recorded holograms and using the corresponding diffraction orders, we will obtain, after recording a rapid process for one exposure, a number of interference patterns in fringes with arbitrary width and orientation with the sensitivity coefficients lying in a broad range from minimal ($K_{\min} = \Delta s_1$) to maximal ($K_{\max} = 2l_{\max}\Delta s_n$) values.

4. Experimental results

We approbated the method for simultaneous recording holograms with different lateral shears by visualising the melting zones of planar polymethyl methacrylate samples during their thermal treatment. The holograms were recorded on Micrat LOI-2 photographic plates with a 2-mm thick glass substrate.

Planar polymethyl methacrylate sample (*4*) was studied on the setup shown schematically in Fig. 1. The object light beam of diameter reduced from 60 to 20 mm with telescopic system (*5, 6*) was incident on four-mirror lateral shear interferometer (*7*). Four photographic plates were placed in series in the planes of recording shear holograms at distances 6, 10, 22, and 30 mm from the plane of the exact coincidence of interfering waves. The holographic angle α_0 was ~ 0.05 rad. In this case, four holograms were recorded during one exposure with the lateral shears along the y axis equal to $\Delta s_1 = 0.9$ mm, $\Delta s_2 = 1.5$ mm, $\Delta s_3 = 3.3$ mm, and $\Delta s_4 = 4.5$ mm.

Figure 3 shows the interference patterns obtained after the optical processing of three of a series of lateral shear holograms recorded for one exposure, which demonstrate a change in the thickness of a planar polymethyl methacrylate sample during thermal treatment. The interference patterns were obtained by using the scheme presented in Fig. 2. In all cases, the $\pm$1st diffraction orders of light from holograms were selected with aperture (*3*). The first pair of interference patterns in fringes of the infinite (Fig. 3a) and finite (Fig. 3b) widths was obtained by using the first hologram recorded with the lateral shear $\Delta s_1 = 0.9$ mm. The two next pairs of interference patterns were obtained by using holograms recorded with lateral shears $\Delta s_2 = 1.5$ mm (Figs 3c, d) and $\Delta s_4 = 4.5$ mm (Figs 3e, f). The sensitivity coefficients of these interference patterns are 1.8 (Figs 3a, b), 3.0 (Figs c, d), and 9.0 (Figs 3e, f).

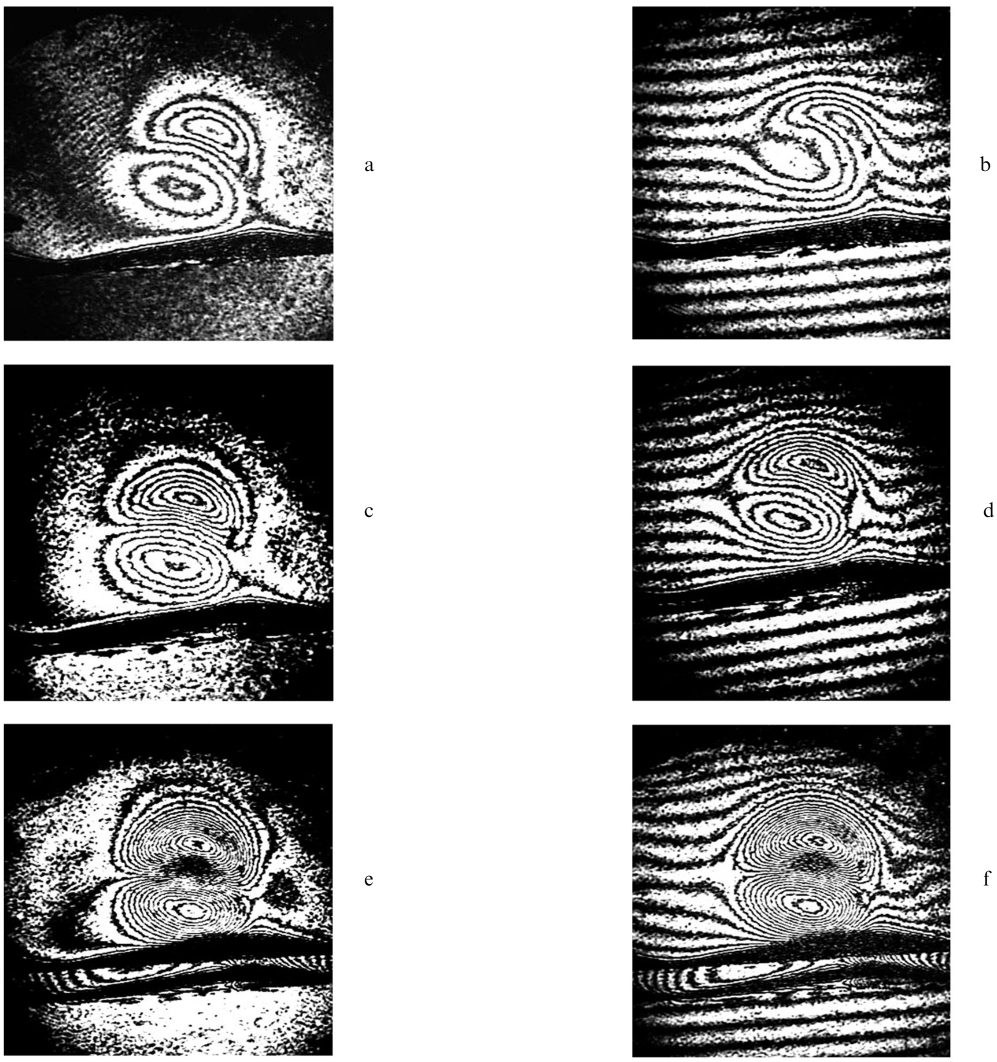

Figure 3. Interference patterns obtained upon optical processing of holograms recorded with lateral shears $\Delta s_1 = 0.9$ mm (a, b), $\Delta s_2 = 1.5$ mm (c, d), and $\Delta s_4 = 4.5$ mm (e, f).

5. Conclusions

Simultaneous recording of a series of holograms with different lateral shears allows one to obtain a quite large number of interference patterns in one experiment, which have a broad range of different sensitivity coefficients, thereby providing the matching between the sensitivity of interference measurements and the value of the measured parameter of an object under study. The method for recording holograms considered in the paper will find applications mainly for studying rapid processes when the range of variation in the measured parameter is uncertain.

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