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Reflection Relief Holography

In the paper the results of the examination of the reflecting relief holograms of great diffraction efficiency (when compared with the transmission holograms of both the amplitude and phase type) have been presented. The first mentions about the application of the reflecting holograms [1] concerned the holograms performed in a conventional way, using the bromo-silver materials. To increase the diffraction efficiency on the diffracted light beams travelling backwards, the surface of the holograms was metallized.

In the present paper the relief holograms were obtained with the help of photopolymers. The obtained phase relief holograms were coated with the metal films of different reflection and absorption coefficients and of different thickness. The wave-front reconstruction by reflecting relief holograms takes place when illuminating its surface with a wave $Q = Q_0 \exp(i\varphi)$ and the reconstructed waves U_r propagate in the direction of the light source [2]. The light field reconstructed with the help of hologram may be described by introducing the concept of the amplitude reflectance R

$$U_r = QR \tag{1}$$

which, when reducing the notation to one dimentional case for the sake of simplicity may be put into the form

$$R(x) = r_a \exp(i\Phi(x)) \tag{2}$$

where x denotes a coordinate in the hologram plane and r_a is an amplitude coefficient characterizing the material of which the relief hologram was made. For conductors [3, 4] we have

$$r_a = K^2 \exp i\delta = \frac{n - i\varkappa - 1}{n - i\varkappa + 1} \tag{3}$$

where K^2 denotes the intensity coefficient of reflection,
δ is a change in the wave phase during reflection on a conductor surface,
$\varkappa$ is the coefficient of the conductor absorption,
n – is the reflection index of the conductor.

The magnitude Φ in formula (2) denotes a change in phase of the incident wave determined by the relief shape containing the holographic information. The relief shape may be described by specifying the relief deepness $d(x)$, which depends on the production technology, the light intensity distribution of the interference field in the hologram plane and the kind of photochemical process applied to registration (Fig. 1).

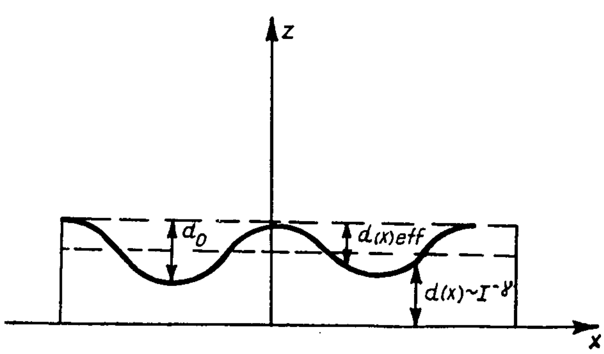

Fig. 1

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$$d(x) \simeq C|S(x)+P(x)|^{-2\gamma}. \quad (4)$$

Here, C and γ are constants characterizing the photochemical process employed, $S(x) = S_0 \exp i\varphi(x)$ denotes a complex amplitude of the object wave, and $P = P_0 \exp i\beta x$ denotes a complex amplitude of the reference wave in the hologram plane, $\beta = \frac{2\pi}{\lambda} \sin\alpha$, where α is an angle between the incidence direction of the reference wave and the normal to the hologram plane (Fig. 2). The reflecting transmittance of the hologram may be represented in the form

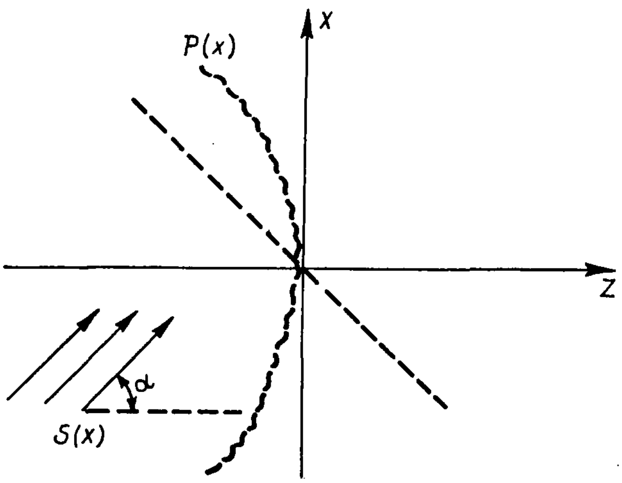

Fig. 2

$$R(x) = r_a \exp(i\, 2k\, d_{\mathrm{eff}}(x)). \quad (5)$$

On the base of the linearity condition typical for the holographic process (5) we get

$$\frac{2S_0(x)P_0(x)}{|S(x)|^2+|P(x)|^2} < 1. \quad (6)$$

When expanding (4) into series and restricting the expansion to the first order terms we obtain

$$d(x) = C[|S(x)|^2+|P(x)|^2]^{-\gamma}\left[1-\gamma\frac{2S_0P_0(x)}{|S(x)|^2(+|P(x)|^2)}\times\right.$$
$$\left.\times\cos(\varphi(x)-\beta x)\right] \quad (7)$$

in particular

$$d_{\mathrm{eff}}(x) = [|S(x)|^2+|P(x)|^2]^{-\gamma}\gamma C\frac{2S_0P_0(x)}{|S(x)|^2+|P(x)|^2}\times$$
$$\times\cos(\varphi(x)-\beta x).$$

Next, expending the term $\exp\,[2\, ik\, d_{\mathrm{eff}}(x)]$ into the Fourier series and exploiting the properties of the Bessel functions $R(x)$ may be put into the form

$$R(x) = r_a J_0(qd_0(x))+2\sum_{n=1}^{\infty}(-i)^n J_n(qd_0(x))\cos\Theta, \quad (8)$$

where

$$d_0(x) = \gamma C\frac{2S_0P_0(x)}{|S(x)|^2+|P(x)|^2},$$

$$q = 2k[|S(x)|^2+|P(x)|^2]^{-\gamma},$$

$$\Theta = \varphi(x)-\beta x.$$

In accordance with (1) the reconstructed wave-fronts arise from the hologram characterized by an amplitude reflectance (8) as a result of its illuminating with a reconstructed wave Q. Each particular term in the expansion may be associated with the corresponding diffraction orders. The zero order term is represented by the term containing J_0, while the first order diffraction, the most important for the holographic practice, is represented by the terms including J_1. The complex amplitude of the diffracted light field of the first order is

$$u_{r_1} = \Theta r_a\,(-i)J_1(qd_0(x))\cos\Theta. \quad (9)$$

Representing J_1 in the form of a series and using again the condition (6) we obtain

$$u_{r_1} = \Theta r_a(-i)qd_0(x)\cos\Theta. \quad (10)$$

Employing (7), we have

$$u_{r_1} = \Theta r_a\frac{\gamma Cq}{|S(x)|^2+|P(x)|^2}S_0P_0(x)\exp\left\{i\left(\varphi(x)-\beta x+\right.\right.$$
$$\left.\left.+\frac{3}{2}\pi\right)\right\}+\Theta\, r_a\frac{\gamma Cq}{|S(x)|^2+|P(x)|^2}S_0P_0(x)\exp\left\{i\left(\beta x-\right.\right.$$
$$\left.\left.-\varphi(x)+\frac{3}{2}\pi\right)\right\}. \quad (11)$$

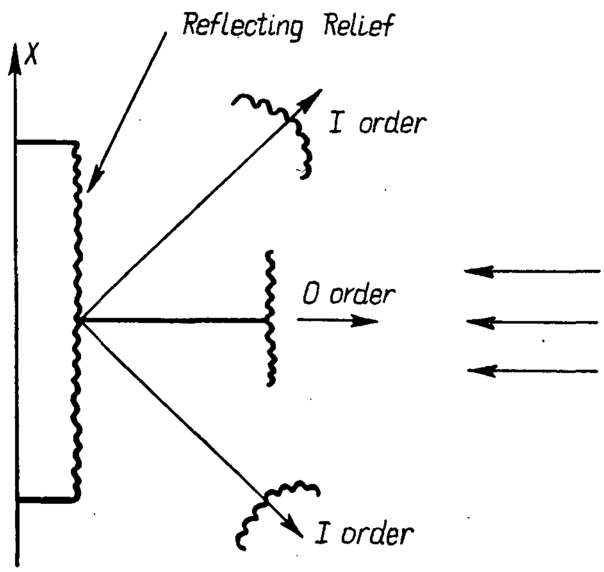

Fig. 3

The object wave-front $S = S_0 \exp(i\varphi)$ is reconstructed in both its phase and amplitude by the diffracted wave (Fig. 3).

Simultaneously from (3) and (11) it can be seen that the brightness of the diffracted bundles may be regulated by using the photomaterials of different reflection index K.

The experiments performed have proved that the reflecting holograms offer great diffraction efficiency amounting to 40%. The latter depends on both the holographic relief deepness as well as the reflection coefficient of the deposited metal. The reflection coefficient may be matched to the wevelength of the light used for reconstruction.

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Problem of the Negative in Holography

1. The Gabor holograms offered possibility of producing both positives and negatives of the diapositive holographic patterns during reconstruction. The amplitude transmittance Tra of a Gabor hologram was given by

$$Tra(x, y) = A_0^2 \pm \frac{dT}{dH}|a(x,y)|^2 \pm \frac{dT}{dH}\left\{A_0 a^* + A_0 a\right\} \tag{1}$$

where $a(x, y) = A_0$ denotes an amplitude of a plane wave illuminating perpendicularly the object to be holographed, $a(x, y) = a_0(x, y)e^{i(x,y)}$ denotes a complex amplitude of an optical field diffracted on the object, (x, y) is the hologram plane, $\frac{dT}{dH}$ is the inclination of the transmittance-exposure characteristic of the photographical material $T = f(H)$ at the working point, where $H = I \cdot t$ and $I = I(x, y)$ is an intensity of the interference field in the hologram plane while t denotes the exposure time. The minus or plus sign of the factor $\frac{dT}{dH}$ corresponds to the negative or respectively positive developing process of the photographic material.

The second term in formula (1) may be neglected because typically

$$|a(x, y)| \ll A_0 \tag{2}$$

for the holographic procedure, condition (2) being the consequence of the linearization of the material characteristic $T = f(H)$ in the vicinity of the working point (2).

From the formula (1) valid for Gabor holograms we obtain two values of the transmittance corresponding to the negative and the positive of the original.

2. For the Leith and Upatnicks method [3] of producing holograms by use of an offset-reference beam, for instance, $A(x, y) = A_0 e^{i2\pi a y}$, where a is the spatial frequency in the hologram plane as well as for the G. Stroke method where a δ source is used, for the reference bundle producing [4] the sign of the factor dT/dH is of no importance, because the reconstructing beam, when applied to a negative hologram or to a positive one, behaves in the identical way. Another words the properties of a hologram as an operator transforming the reference beam into the image wave should be invariant with respect to the operation of the positive/negative conversion both for the amplitude transmition holograms and the phase transmition ones, as well as for the reflectance (or mixed) type holograms [5]. Nevertheless, the question may be risen if it would be possible to influence the contrast in a reconstructed image with

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