

ON THE POSSIBILITY OF OBTAINING HOLOGRAMS USING A REFERENCE BEAM WHOSE WAVELENGTH DIFFERS FROM THE WAVELENGTH OF THE RADIATION SCATTERED BY THE OBJECT

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Abstract

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PHYSICS

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ON THE POSSIBILITY OF OBTAINING HOLOGRAMS USING A REFERENCE BEAM WHOSE WAVELENGTH DIFFERS FROM THE WAVELENGTH OF THE RADIATION SCATTERED BY THE OBJECT

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One of the basic conditions for obtaining a hologram by the Gabor method ⁽¹⁾ is the strict phase coherence of the oscillations of the waves interfering in its plane. This circumstance limits the range of applications of the holographic method to the case of objects that are located close together and remain stationary during the exposure.

Below we discuss the possibility of obtaining holograms in the case when the condition of phase coherence is not fulfilled. In our consideration we shall use a method of reasoning analogous to ⁽¹⁾, which is applicable to a plane hologram of any type. We define the wave functions of the radiation scattered by the object and of the reference beam by the expressions

$$\Psi_0 = a_0(r) \exp[ik_0 L_0(r)] \exp[i\omega_0 t]; \quad (1)$$

$$\Psi_s = a_s \exp[ik_s L_s(r)] \exp[i\omega_s t], \quad (2)$$

where r is the radius vector of an arbitrary point of the hologram; $k_0 = 2\pi/\lambda_0$; $k_s = 2\pi/\lambda_s$; λ_0 and λ_s are the wavelengths of the radiation scattered by the object and of the reference beam. The eikonals L_0 and L_s are assumed not to depend on the wavelength, which for narrow spectral ranges outside absorption lines is apparently permissible. The intensity distribution of the total wave field Ψ_h in some plane P is found by adding (1) and (2) and multiplying the result by the complex conjugate quantity:

$$\Psi_h \Psi_h^* = a_0^2(r) + a_s^2 + 2a_0(r)a_s \cos[(\omega_0 - \omega_s)t + k_0 L_0(r) - k_s L_s(r)]. \quad (3)$$

Expression (3) describes traveling intensity waves, whose spatial configuration is determined by the function $k_0 L_0(r) - k_s L_s(r)$. With direct recording on a photographic plate, such a traveling interference pattern forms a uniform background. However, this pattern can be preserved, for example, by placing in front of the photographic plate an inertia-free optical shutter whose transmission coefficient is proportional to the field intensity at some reference point of the photographic plate with coordinate r_0 . In this case the reference point must be located outside the optical shutter.* The radiation-intensity distribution on the photographic plate in this case can be found by multiplying expression (3) by the value of the intensity at the point r_0 :

$$\begin{aligned} \Psi_{hT} \Psi_{hT}^* = C_0 \Psi_h \Psi_h^*(r) \Psi_h \Psi_h^*(r_0) = C_1 + C_2 \cos[(\omega_0 - \omega_s)t + \varphi_1(r_0)] \\ + C_3 \cos[(\omega_0 - \omega_s)t + \varphi_1(r)] + C_4 \cos[2(\omega_0 - \omega_s)t + \varphi_2(r, r_0)] \quad (4) \\ + C_5 \cos\{k_0[L_0(r) - L_0(r_0)] - k_s[L_s(r) - L_s(r_0)]\}, \end{aligned}$$

where C_0 - C_5 and φ_1, φ_2 are certain constants. The first through fourth terms describe a constant background, a background harmonically varying in time, and traveling waves of various structure. The fifth term of (4) describes

* The optical shutter mentioned is necessary only when recording the hologram directly on a photographic plate. With photoelectric registration, operations (4) and (6) can be carried out in electronic circuits.

a stable interference pattern. However, a change in the quantities k_0 and k_s during the exposure will lead to smearing of the photographic image of the interference pattern far from the reference point r_0 , whereas near it the photographic image will remain sharp. The condition for preserving the interference pattern over the entire photographic plate can be written as follows:

$$\{\Delta k_0[L_0(r) - L_0(r_0)] - \Delta k_s[L_s(r) - L_s(r_0)]\}_{\max} \leq \pi, \quad (5)$$

where Δk_0 and Δk_s are the increments of k_0 and k_s during the exposure.

If we assume that the amplitude transmission coefficient T_h of the exposed and developed photographic plate is proportional to the intensity of the radiation exposing it, and take into account that the radiation described by the first terms of (4), for exposure times $t_{\text{exp}} \gg 2\pi/(\omega_0 - \omega_s)$, forms a uniform background, we obtain

$$\begin{aligned} T_h = T_0 + ca_0(r) \exp\{i\{k_0[L_0(r) - L_0(r_0)] - k_s[L_s(r) - L_s(r_0)]\}\} + \\ + ca_0(r) \exp\{-i\{k_0[L_0(r) - L_0(r_0)] - k_s[L_s(r) - L_s(r_0)]\}\}. \quad (6) \end{aligned}$$

Let, during reconstruction, radiation from the reference source be incident on the hologram. The value of the wave function behind the hologram is found by multiplying (2) by (6):

$$\begin{aligned}\Psi_p = T_h \Psi_s = T_0 a_s \exp[ik_s L_s(r)] \exp[i\omega_s t] + c a_s a_0(r) \exp\{i[k_s L_s(r_0) - k_0 L_0(r_0)]\} \exp[ik_0 L_0(r)] \exp[i\omega_s t] \\ + c a_s a_0(r) \exp\{i[k_0 L_0(r_0) - k_s L_s(r_0)]\} \exp\{-i[k_0 L_0(r) - k_s 2L_s(r)]\} \exp[i\omega_s t].\end{aligned}\quad (7)$$

The second and third terms of (7) are almost completely analogous to the terms that describe the virtual and real images in the corresponding expression of Gabor's holographic method. The difference consists in the appearance of an inessential constant depending on the choice of r_0 , and also in the fact that the amplitude-phase part of these expressions coincides with the amplitude-phase part of the radiation scattered by the object (1), while the time part coincides with the time part of the wave function of the reference beam (2). Introducing a new value of the eikonal

$$L'_0(r) = \frac{k_0}{k_s} L_0(r)$$

and combining all constants, the wave corresponding to the virtual image of the object can be written in the form

$$\Psi_m = A a_0(r) \exp[ik_s L'_0(r)] \exp[i\omega_s t]. \quad (8)$$

Comparing (8) and (1), we note that in (8) the eikonal and the wavelength have been replaced. Replacement of the eikonal in the case $\lambda_s - \lambda_0 \ll \lambda_s \lambda_0$ indicates a slight displacement and change in the dimensions of the object image, while the change in wavelength will slightly alter the spectral composition of the reconstructed image.

In conclusion, let us dwell on some questions connected with the practical realization of this method. The difference in wavelengths of the signal and reference beams may be caused by a Doppler shift in recording a moving object, by changes in the spectral composition of the laser radiation when the beams mentioned are formed from successive pulses of one and the same source, by a difference in the wavelengths of two lasers, etc. Wavelength shifts due to the listed causes are quantities of the order of hundredths of an angstrom (see, for example, (2)). In the visible range this corresponds to beats with frequency $\omega_0 - \omega_s$ of the order of hundreds of megahertz, which is within the capabilities of techniques for reception and modulation of radiation.

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CITED LITERATURE

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2. M. Hercher, Appl. Phys. Let., **7**, 39 (1965).

Note: Figure translations are in progress. See original paper for figures.

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