HOLOGRAPHIC RECORDING OF NONSTATIONARY PROCESSES

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The purpose of most works on holography is to obtain static images of immobile objects. In those cases when the object moves appreciably during the exposure time, special measures are adopted (see [1]) to prevent the motion of the object from deteriorating the sharpness of the image. One can attempt, however, not to avoid the displacements, but to use the holography to record the motion process itself. In the present paper we propose a method for continuously recording the temporal variations of the wave front. The method is based on using a specially shaped reference beam.

Assume that a plane wave (signal) is normally incident on a photographic plate. The field of the wave on the plate is given by

$$E(t) = \mathcal{E}(t)\exp[-i\omega t].$$

Auxiliary radiation (reference beam) is aimed at the same plate. Unlike in ordinary holography, the reference beam is not monochromatic, and the radiation frequency varies linearly over its cross section. In the plane of the plate, the field of the reference beam is given by

$$\exp[-i\omega t + i\frac{\omega}{c}x\sin\alpha + iaxt\cos\alpha]. \qquad (1)$$

Here α is the angle between the reference beam and the normal to the plate. An important characteristic of the reference beam is the product of the constant a (the rate of change of the frequency over the cross section) and the beam width D. The quantity aD gives the total change of the frequency in the entire cross section; this quantity should span the required frequency spectrum of the investigated signal.

The joint action of the investigated signal and the reference signal produces on the photographic plate (accurate to a proportionality factor) a photographic density

$$S(x) = S_0 + \int\mathcal{E}(t')\exp[-iaxt'\cos\alpha]dt' + \text{compl. conj.}, \qquad (2)$$

where S_0 does not depend on x. Thus, the transmission contains information concerning the Fourier transform of the investigated signal (the second term in formula (2)). We emphasize that we register here temporal Fourier components.

To reproduce the signal, the inverse Fourier transform is taken. A restoring light beam, formed in accordance with the same principle as the reference beam, but possibly with a different rate of change of the frequency over the beam cross section, is incident on the photographic plate. The field of the restoring wave in the plane of the plate is given by

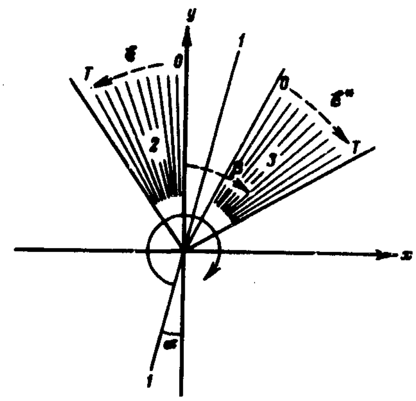
$$\exp[-i\omega t + i\frac{\omega}{c}x\sin\alpha + ibxt\cos\alpha].$$

In the far zone behind the plate there will be observed, at zero angle, a field of the form

$$\tilde{\mathcal{E}}\left(\frac{b}{a}t\right)\exp[-i\omega t].$$

The function $\tilde{\mathcal{E}}$ does not coincide exactly with the initial signal $\mathcal{E}$ but is a convolution of the initial signal $\mathcal{E}$ with a certain apparatus function of width

$\Delta t = (aD)^{-1}$. Thus, the initial signal is reproduced with a time resoltuion Δt. We emphasize that when the signal is reproduced it is stretched in time in a ratio a/b.



Schematic image of reconstructed field in the far zone: 1 - initial direction of restoring beam; 2 - reproduced signal at the initial instant of restoration; 3 - conjugate signal at the initial instant of reconstruction. The picture rotates in the direction indicated by the solid arrow.

Calculation shows that in the reconstruction the far-zone field is given by

$$\tilde{\mathcal{E}}\left(\frac{b}{a}t - \frac{\omega}{c}\frac{1}{a}\frac{\sin\beta}{\cos\alpha}\right)\exp[-i\omega t],$$

where β is the observation angle. The signal occupies a certain angle interval (see the figure), with different angles β corresponding to the different instants of time of the signal. In particular, if a monochromatic restoring beam is used (b = 0), it is possible to obtain a static picture in which the time dependence is converted into an angular dependence.

The conjugate signal at each instant of time is symmetrical to the main signal about the propagation of the non-diffracted beam, and is given by

$$\tilde{\mathcal{E}}^*\left(-\frac{b}{a}t + \frac{\omega}{c}\frac{1}{a}\frac{\sin\beta - 2\sin\alpha}{\cos\alpha}\right)\exp[-i\omega t].$$

A reference beam with the required properties can be shaped from the radiation of a single-mode laser by rotating mirror or by using a special electrooptical cell. This cell should be made of two prisms, one increasing the refractive index and the other decreasing it when the voltage is applied. At an electrooptical coefficient $r = 10^{-7}$ cm/V (KDP crystal at -100°C) and a voltage 10^4 V, it is possible to obtain, by using a cell with dimensions on the order of several centimeters, a ratio $T/\Delta t = 1000$ of the total duration T to the resolved interval. In particular, it is possible to expect here a time resolution $\Delta t \simeq 10^{-12}$ sec (see [2]).

We considered above registration of functions of only one variable - the time - and accordingly the information recorded in the hologram (photographic density) was a function of only one coordinate x. An obvious generalization of this method is to use two coordinates on the photographic plate, recording as before the temporal information along the x axis, and the dependence of the signal on one of the spatial coordinates along the y axis. Even more important is the problem of recording a function of two spatial coordinates and the time. This is possible by using a three-dimensional photographic emulsion and a reference beam of the type considered above. It must be emphasized that in this case one records both the amplitude and the phase of the registered light field. This means that the reconstruction can yield a three-dimensional picture that depends on the time.

[1] Yu.N. Denisyuk, D.I. Stasel'ko, and V.P. Minina, Opt.-Mekh. Prom. No. 11, 73 (1968).

[2] V.A. Zubov, A.V. Kraiskii, and T.I. Kuznetsova, Patent Disclosure No. 1373640/25 - 26; Abstracts of Papers Delivered at the Fifth All-union Conference on Nonlinear Optics, MGU, 1970, p. 155.