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by

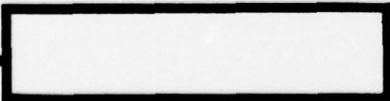
M. G. Girina, V. I. Mandrosov  
and G. A. Sobolev



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Estimation of the Density of a Latent Image using a  
Holographic Method

by

M.G.Girina, V.I.Mandrossov, and G.A.Sobolev

Among the various methods of investigating latent images a great deal of interest has been in the holographic method of visualization, which allows one to investigate the dynamics of the growth of the latent image, as in [1]. The difficulty of direct photographic observation of the growth of the latent image is connected with the problem of recording small densities. The photographic methods suggested in [2,3] allow one to record optical densities on the order of  $10^{-3}$ — $10^{-4}$ .

However, it must be observed that the photographic methods are based on the measurement of two relatively large (in magnitude) light signals, and on the determination of the difference between them, by the balance method. It is clear that even insignificant diffusion of light can lead to large errors in similar measurements. In addition, there are also severe requirements on the uniformity of the specimen, the stability of the light flux, and so forth.

Also, the photographic method allows one to measure only the constant density of the photographic image, and can not be used for recording small densities, containing large spatial frequencies, which are more interesting from the point of view of holographic applications.

In order to observe the continuous growth of the latent image in one sample of photomaterial, using these methods, definite technical problems must be overcome.

In the present work we examine a method of holographic measurement of the growth of the latent image, suggested in [1]. This method is distinguished from the photographic method by virtue of the properties of the hologram, which allow one to obtain the difference signal, so long as the radiational deviation produced by the hologram arises due to insignificant modulation of the optical density.

Measurements are conducted using the usual holographic scheme, with a split beam (fig.1). Plane wave fronts from a helium-neon laser are split with an optical wedge into two planar beams. The interference pattern of the two planar beams is recorded on a photographic plate with an improved Lippman emulsion, of type PE-1. As a result of the interaction of the light with the microcrystals of silver halide latent image centers are formed, and a hologram is produced with an everywhere small optical density.

The period of the transmission function of the hologram is equal to the period of the interference pattern between the reference and object beams. Each of these beams (reference and object) has undergone diffraction in forming the hologram, and the same is true of the reconstructed beam.

As a result of the diffraction several diffraction orders are formed, which can be registered by highly sensitive photoreceivers equipped with a photomultiplier and cathode follower with a sensitive and low-inertia galvanometer. Weak diffraction orders can also be observed visually in a microscope.

FIG. 1. SCHEME OF THE OBSERVATIONAL SET-UP USED TO STUDY GROWTH OF LATENT HOLOGRAPHIC IMAGE 1 - PLANE WAVE FRONT FROM HELIUM-NEON LASER 2 - OPTICAL WEDGE 3 - PHOTO. PLATE WITH LIPPMAN EMULSION 4 - LENS 5 - PLANE OF OBS. OF THE FOCUSED DIFFRACTION ORDERS 6 - PHOTORECEIVER

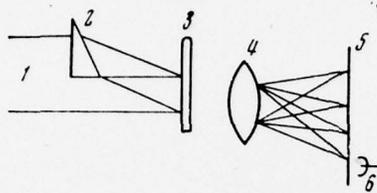


Fig. 1

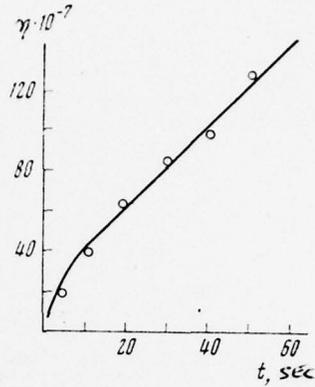


Fig. 2

The results of our measurements are presented in fig. 2 in coordinates of time of exposure, in seconds, versus diffraction effectiveness. The experimental curve shows that the growth of the diffraction effectiveness is proportional to the time of exposure in a satisfactorily wide range of exposure times, from several seconds to one hour (where the power of the radiation from the helium-neon laser impinging on the photoreceiver is of the order  $10^{-4}$  watt). Under these conditions the maximum sensitivity of the photoreceiver, with the photomultiplier, is about  $10^{-12}$  watt.

We pass now to a theoretical investigation of the connection between diffraction effectiveness and the optical density of the darkened areas.

In as much as the intensity of the interference pattern recorded on film is periodic, the amplitude of the transmission function, which arises as a result of the diffraction grating, can be expanded in a Fourier series:

$$\tau_a = \tau_0 + \tau_1 \cos 2\pi\nu x + \tau_2 \cos 4\pi\nu x + \dots,$$

where

$$\tau_1 = \frac{2\pi}{S_r} \int \tau_o \cos 2\pi\nu x dx,$$

$$\tau_2 = \frac{2\pi}{S_r} \int \tau_o \cos 4\pi\nu x dx,$$

$\nu = \frac{\sin \theta}{\lambda}$  is the spatial frequency,  $2\theta$  is the angle of convergence of the reference and object beams.

As a result of reconstruction there arises the following amplitude distribution:

$$E_e = \tau_o E_p = [\tau_o + \tau_1 \cos 2\pi\nu x + \tau_2 \cos 4\pi\nu x] E_p,$$

where  $E_p = [E_o e^{i\nu x} + E_n e^{-i\nu x}]$  is the composite reconstructed signal.

In this manner, the hologram will form a series of plane waves with amplitudes:

$$E_o^0 = \tau E_o; \quad E_o^{\pm 1} = \tau_1 E_o; \quad E_o^{\pm 2} = \tau_2 E_o$$

and so forth (orders corresponding to the reference beam),

$$E_n^0 = \tau_o E_n; \quad E_n^{\pm 1} = \tau_1 E_n; \quad E_n^{\pm 2} = \tau_2 E_n$$

and so forth (orders corresponding to the object beam).

In certain directions certain waves partially coincide. For example, order +1 waves from the reference beam are formed in the direction of zero order waves from the object beam, -1 order waves from the object beam correspond to +1 order waves from the reference beam, +2 order waves from the object beam are formed in the direction of -1 order waves from the reference beams, etc.

The radiative power corresponding to these orders is:

$$P_o^0 = E_o^2 \tau_o^2 S_r, \quad P_o^{\pm 1} = E_o^2 \tau_1^2 S_r \quad \text{и} \quad P_o^{\pm 2} = E_o^2 \tau_2^2 S_r,$$

$$P_n^0 = E_n^2 \tau_o^2 S_r, \quad P_n^{\pm 1} = E_n^2 \tau_1^2 S_r \quad \text{и} \quad P_n^{\pm 2} = E_n^2 \tau_2^2 S_r.$$

The diffraction effectiveness is:

$$\eta = \frac{P_n^{+1}}{E_n^2 S_r} = \frac{P_0^{+1}}{E_0^2 S_r} = \tau_1^2.$$

In the experiment what was recorded, in fact, was the total fields: either  $E_n^{+1} + E_0^{+2}$ , or  $E_0^{+1} + E_n^{-2}$ ; the power of the second orders is significantly smaller than the power of the first orders, so that in practice we measure a value equal to either  $P_0^{+1}$  or  $P_n^{-1}$ .

Experimentally we obtained the following approximate relationship between  $\eta$  and the exposure time, useful over a wide range of exposure times:

$$\eta \approx \alpha t_{\text{exp}} = \tau_1^2.$$

In this manner  $\tau_1 = \sqrt{\alpha t}$ , where  $\alpha$  depends on the average value of the intensity of the interference pattern. Thus, ignoring the second orders of diffraction, we get

$$\tau_a = \tau_0(t) + \sqrt{\alpha t} \cos 2\pi vx,$$

where  $\alpha = \alpha(I)$ ,

$$I = 2I_0(1 + k^2 + 2k \cos 2\pi vx),$$

$$I = 2I_0(1 + k^2), \quad k = \frac{E_n}{E_0}.$$

$E_n$  is the amplitude of the object beam, and  $E_0$  the amplitude of the reference beam.

To implement the experiment we took  $k=1$ .

We determined the further increase of the density of the darkened area in the formation of the latent image.

Defining  $\tau_a = 10^{-\frac{D(x)}{2}}$  we obtain

$$D(x) = -\frac{2}{2.3} \ln \tau_0 \left( 1 + \frac{\tau_1}{\tau_0} \cos 2\pi vx + \frac{\tau_2}{\tau_0} \cos 4\pi vx \right).$$

Expanding the above expression in terms of the parameters  $\tau_1$  and  $\tau_2$  and discarding small terms, we get:

$$D(x) = D_0(x) + \left[ \frac{\tau_1}{\tau_0} \cos 2\pi vx + \frac{\tau_2}{\tau_0} \cos 4\pi vx \right],$$

where  $D_0 = -2 \lg \tau_0$  the average optical density, which, in practice, is close to the original optical density. Ignoring the secondary orders of diffraction we obtain the increase in the density of the darkened area:

$$\Delta D = \frac{\tau_1}{\tau_0} \cos 2\pi vx = \frac{\sqrt{\alpha t}}{\tau_0} \cos 2\pi vx = \frac{\sqrt{\eta_{\pm 1}}}{\tau_0} \cos 2\pi vx.$$

From the preceding relation it follows that the amplitude of the measured density of the darkened areas is proportional to the square root of the diffraction effectiveness. The simplicity of this result facilitates using this method in the investigation of small densities.

The minimal diffraction effectiveness which we measured was:

$$\eta = \tau_1^2 \approx 10^{-7}.$$

Then, taking  $\tau_0 \approx 1$  we obtain:

$$\Delta D \approx 3 \cdot 10^{-4} \cos 2\pi vx.$$

From this it is clear that the minimally registered amplitude, obtained in our experiment, is of the order  $3 \cdot 10^{-4}$ , which coincides with the result obtained by the photographic method [2,4].

In this manner both our experiment and the theoretical analysis show that the holographic method allows

one, in a simple and accurate manner, to measure, in real time, insignificant darkening densities, dictated by the formation of the holographic image.

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Pedagogical Institute

Submitted  
12-20-1971

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