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An improvement of the holographic imaging quality by the method of noncoherent superposition of images*

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A considerable improvement of the holographic imaging quality has been gained by using the following method of noncoherent superposition of images: Several holograms corresponding to several spatially separated reference beam have been recorded at the same place of the holographic plate, the phase distribution in the object beam being changed before each exposure. In the reconstruction the images, reconstructed from the subsequent holograms by means of the respective reference beams, were recorded at te same place in the recording material which allowed to obtain noncoherent superposition of the images.

Introduction

It is well-known that the images formed in the optical systems with laser light illumination, including the holographic images, are of considerably lower quality if compared with those formed by the optical systems with noncoherent illumination. This is caused by some detrimental phenomena associated with laser illumination, like speckling and coherent noise understood as unwanted diffraction and interference effects. These phenomena have a negative influence on the holographic image quality during the process of both recording and reconstructing of the image.

There exists a number of methods of coherent noise supression in the nonholographic systems, but only some of them may be exploited in holography. The most simple and effective method consists in applying a rotating ground glass. This method cannot be used in the process of holographic recording, because the rotating ground glass destroyes the phase relations in the laser beam which makes it impossible to produce a hologram; there are, however, some modifications of the method meeting the needs of holography. First of them described by MARTIENSSEN and SPILLER [1] consists in making several lensless Fourier holograms, while a ground glass inserted in the beam illuminating the object is shifted before each hologram exposure. In the reconstruction the holograms are subsequently introduced in a sta-

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tionary reconstructing beam, nad the reconstructed images are recorded photographically at the same place of the photographic plate. The resulting image is thus due to noncoherent superposition of several holographic images differing in the phase distribution. Thank to this in the case of sufficiently great number of images superposed with the respectively high accuracy the resulting image of the object is of almost the same quality as that obtained for the noncoherent illumination. An effective operation of this method requires that the error of superposition of particular holographic images be less than the resolving power of the system which is difficult to satisfy in practice.

The Martienssen–Spiller method was modified by other authors who used different methods to obtain noncoherent superposition of images. For example, noncoherent superposition of images in the holographic microscope was applied in [2]. Several coherent laser beams incident on the object under different angles were used for recording. During the reconstruction of such holograms a number of foci corresponding to the particular illuminating beams appeared within the pupil together with the respective spectrum of the rays diffracted at the object. In the optical system pupil a diaphragm was inserted with an aperture of such diameter, that the spatial frequency spectrum of the object was transmitted for one illuminating beam only, while the light from the other beams was stopped. This diaphragm was shifted during the photographic recording to select the subsequent images corresponding to different object beams. Thus, the noncoherent superposition of these images at the same place of the recording material became possible. The coherent noise having its source outside the object plane was averaged, creating more or less uniform background depending on the number of superposed images. The resolving power of such system depends upon the size of the moving diaphragm aperture. As the application of the diaphragm causes a decrease in system aperture the resolving power of the optical system is also reduced. The method of noncoherent superposition of the holographic images was applied also in the system of holographic microscope with the pulsed laser [3]. Several one-exposure holograms differing in the phase distribution in the object beam were recorded simultaneously. Next, a system composed of helium–neon laser and a rotating ground glass was used to the reconstruction and the holographic images reconstructed from the subsequent holograms were superposed. In the paper [4] a special phase-amplitude grating was applied in the process of two-exposure recording of Fourier-hologram; the grating being moved between the exposures. During the exposure the hologram was illuminated simultaneously by the reference beams emitted by two lasers and the image produced by noncoherent superposition of the images reconstructed by these beams was recorded.

The method of improving the holographic images presented in this paper is also a modification of noncoherent superposition of the images. It consists in dividing the reference beam into several spatially separated beams, which serve subsequently to multi-exposure hologram recording. The phase distribution in the object beam is changed between the subsequent exposures. In the reconstruction the holographic images are reconstructed with respective reference beams at the same place of the photographic material, thus realizing its noncoherent superposition.

Experimental setup

The optical scheme of the experimental setup is shown in fig. 1. To divide the laser beam into four spatially separated reference beams and the object beam a light dividing system was used. It was composed of four partially transmitting mirrors: T_1, T_2, T_3, T_4. Their reflection coefficients were selected so that all the reference

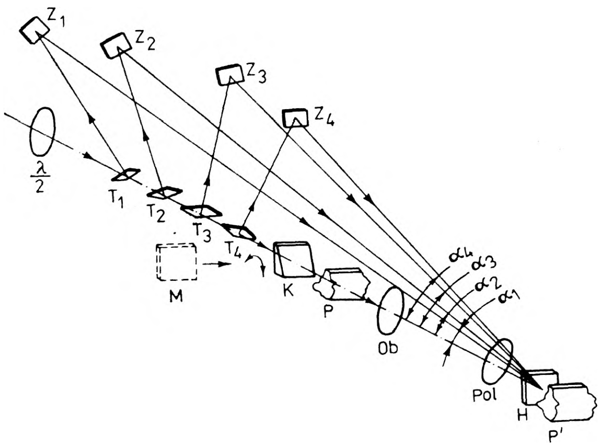

Fig. 1. Scheme of the experimental setup

beams had their intensities close to one another. An accurate equalization of the intensities in the reference beams and the fixation of the proper ratio of the reference beams intensity to that of the object beam were realized by using a half wave plate $\lambda/2$ and a polarizer Pol. The reference beams were directed to the hologram H with the help of four totally reflecting mirrors Z_1, Z_2, Z_3, Z_4, while each reference beams created the angle $\alpha = 30°$ with respect to the object beam. The hologram was recorded at a small distance from the plane of sharp imaging P' of the object P imaged by the objective *Ob*. In front of the object there was a thin wedge K which, being stepwisely inclined between the exposures, introduced the respective changes in the phase distribution in the object beam. This wedge could be replaced by a ground glass M shifted along the object beam between the exposures.

Results of experiments

In the described systems a number of experiments concerning the holographic imaging improvement have been made, both under conditions of diffuse and nondiffuse illumination of the object. A photographic test containing line pairs of different densities as well as several biological specimens were used as the objects.

In the experiments with the diffuse illuminated object the ground glass was placed in the object beam and a four-exposure hologram was produced by applying subsequent reference beams and changing the position of the ground glass between the exposures. The time of exposure was equal to 1/4 of that to single-exposure hologram. The hologram after development was located again at the position identical with that of recording. During reconstruction the subsequent images reconstructed from the hologram with the same beams which played the part of the reference beams in the recording process were superposed on the photographic plate positioned in the image plane P'. Thus a noncoherent superposition of four images is obtained. The result of this noncoherent superposition is presented in fig. 2b, while fig. 2a shows an image reconstructed from the one-exposure hologram which was produced with one beam chosen from the set of reference beams used during recording. A comparison of the images presented in figs. 2a and 2b allows to conclude that

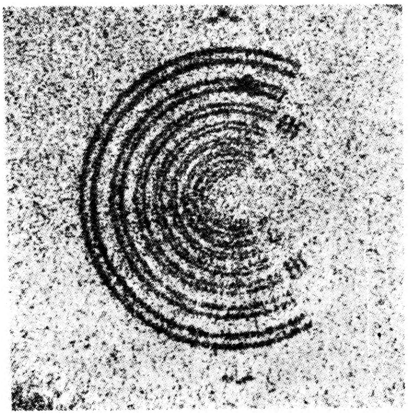

Fig. 2a. Image of test reconstructed from the one-exposure hologram. Diffuse illumination of the object

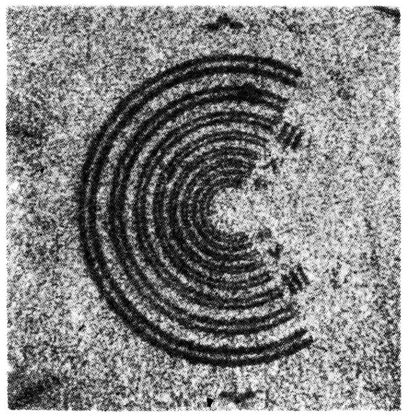

Fig. 2b. Test image obtained due to noncoherent superposition of four holographic images. Diffuse illumination of the object

the method of noncoherent superposition of images results in considerable improvement of the imaging quality. It may be easily seen that the contrast of the speckling images has been drastically reduced, the last lines become continuous while their edges — smooth. The noncoherent superposition of images resulted also in an improving of the resolution of the imaging. In the fig. 2b the sixth group of test lines is well resolved, while the lines of the same group shown in fig. 2a are not resolved.

In the experiments carried out for nondiffuse illumination of the object the ground glass was removed from the optical system and a wedge K was inserted instead (fig. 1). During four-exposure hologram recording the position of the wedge in the object beam was changed between the exposures which resulted in respective changes in the phase distribution. After processing the hologram is set at the recording position. In the reconstruction the subsequent images, reconstructed from the hologram with the same beams which played the part of the reference beams during recording, were superposed on the photographic plate. These images correspond to the respective changes in the wedge position along the object beam. The results of the noncoherent superposition of the images are presented in figs. 3b and 4b, while the images reconstructed from the one-exposure hologram are shown in figs. 3a and 4a for comparison. It is easy to notice that the images reconstructed from the one-exposure holograms are hardly readable, due to high noise level. The edges of test lines in fig. 3a being discontinuous, and the line width is difficult to determine. The image of the biological specimen in fig. 4a is also of very poor quality. High contrast line fringes superposing with the proper image are caused by the interference effects in the half-transparent mirrors. The images obtained by the method of noncoherent

Fig. 3a. Image of the test reconstructed from one-exposure hologram. Diffuse illumination

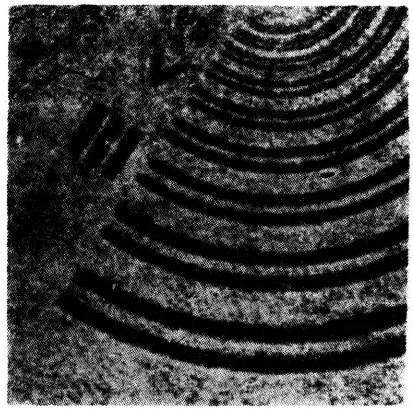

Fig. 3b. Image of the test obtained by noncoherent superposition of four holographic images. Nondiffuse illumination

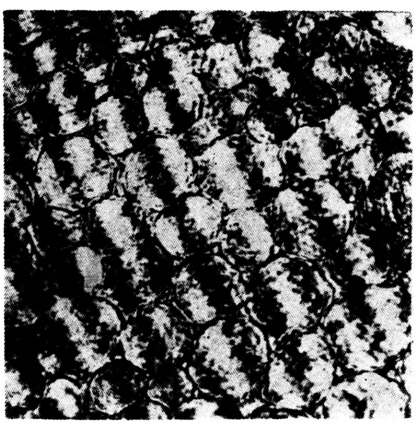

Fig. 4a. Image of a biological specimen reconstructed from one-exposure hologram. Nondiffuse illumination

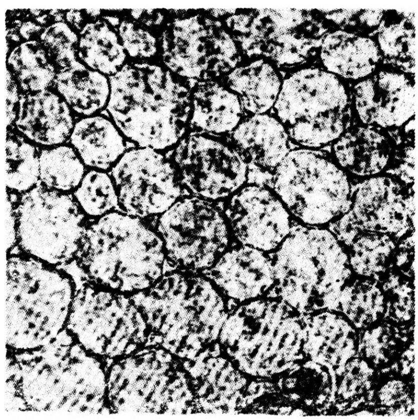

Fig. 4b. Image of a biological specimen obtained by noncoherent superposition of four holographic images. Nondiffuse illumination

superposition presented in figs. 3b and 4b are of definitely better quality. High contrast noises and, in particular, the fringes visible in fig. 4a is smeared. The readability of the image is improved, the edges of the test lines are smoothed and the lines are of equal thickness along their whole length. In the experiments described no spatial filtration of either the reference or the object beams was used, hence it may be concluded that with filtration the images obtained by noncoherent method would be of still higher quality.

Conclusions

The results obtained indicate that the proposed method of noncoherent superposition of several holographic images corresponding to different reference beams and different phase distribution in the object beam results in a distinct improvement of the image quality by increasing its readability and definition.

The method described gives a number of advantages if compared to other methods of this kind mentioned in the introduction. It does not cause any decreasing of the resolving power or the depth of the holographic imaging. It does not require the usage of several lasers and allows to avoid the tedious adjustment of the superposed-images. In order to obtain the overlapping of the images it suffices to assure the respective repositioning of the hologram to put it again at the recording position. A further improvement of the imaging quality may be expected by applying this method of noncoherent superposition in the system if spatial filtering of the beams is also used.

This method was primarily elaborated for application in the microscopy and holographic interferometry, but due to many-exposure techniques of recording it cannot be used in the cases of high speed phenomena. Besides the application of many-exposure recording of holograms causes some decrease in their diffraction efficiency.

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Улучшение качества голографического отображения методом несвязного наложения изображений

Было достигнуто значительное улучшение качества голографического отображения, применяя следующий метод несвязного наложения изображений: В том же месте голографической пластины было зарегистрировано несколько голограмм, соответствующих нескольким пространственно разделенным пучкам отнесения, причём перед каждой экспозицией изменялось распределение фазы в предметном пучке. В ходе реконструкции, изображения, отображаемые по очередным голограммам с помощью соответствующих пучков отнесения, записывались на том же месте регистрирующего материала, благодаря чему было достигнуто несвязное наложение изображений.