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A Multiple Coincidence Holographic Method of Obtaining a Number of Dynamic Process Records

This, here presented, new method of coincidence holographic records is based upon a fundamental feature of holographic registration: the necessity of a simultaneous existence of two coherent waves in the recording plane. Time and space separations of subsequent records are as the result of interference zone movement in the recording plane. Using very short and high energy laser pulses it is possible to obtain a number of separate holographic records of dynamic or moving objects. This method eliminates the need of applying any movable parts in the arrangement.

1. Introduction

Visualization of dynamic processes should provide sufficient information about the development of investigated processes vs. time. There are well known photographic methods of quick registration, for instance:

— film cameras with optical stopping of the images; the rate of registering of these systems can achieve magnitudes of 10^5 frames per second;

— photo cameras equipped with lens matrices; in these systems the rate of several millions per second can be achieved.

Speeds higher than those mentioned above can be obtained in electrooptically converting cameras — here the register speed can reach even several hundred millions of frames per second. In all these methods the photographic images are as the final products and the analysis of the development vs. time of tested processes requires relative big changes of successive states. Such kinds of visualization are, moreover, two-dimensional ones, if three-dimensional display is desired two or more cameras should be applied.

The other essential problem associated with very high speed registration concernes selecting of the source for lightning processes. The time periods of separate exposures are extremally short and the light source should provide very high power to ensure sufficient light energy falling on separate records. In a number of modern high-speed cameras lasers used as light sources provide a sequence of nanosecond light pulses and resolve at the same time shutter problems. It must be mentioned, however, that the basic feature of laser light i.e. coherence is not utilized in these systems. Moreover, the coherence of laser light is often considered as a serious disadvantage, causing grain structure of the images.

The basic aim of this paper is to point out some possibilities, which can be achieved by using coherent illumination of dynamic processes during their registration. The method here proposed makes it possible to obtain multiple holographic records distributed in time and space. Since it is possible to produce an interference pattern two holograms registered successively one after another so there exists a possibility of distinguishing the two corresponding successive states (of the object under test) even if they differ from each other by as little as $\lambda/2$ of the laser light used.

2. General Description on the Arrangement

The basic aim of the experiment was to obtain a series of holographic records of a developing dynamic process, providing sufficient distribution in time and space between separate records. The general principle of the arrangement is shown in Fig. 1. Let us suppose, there is for our disposal a single laser pulse of the duration time satisfying two following conditions simultaneously:

$$\tau_i \ll T \tag{1}$$

and

$$\tau_i \leq \frac{0.1\lambda}{V_{max}}, \tag{2}$$

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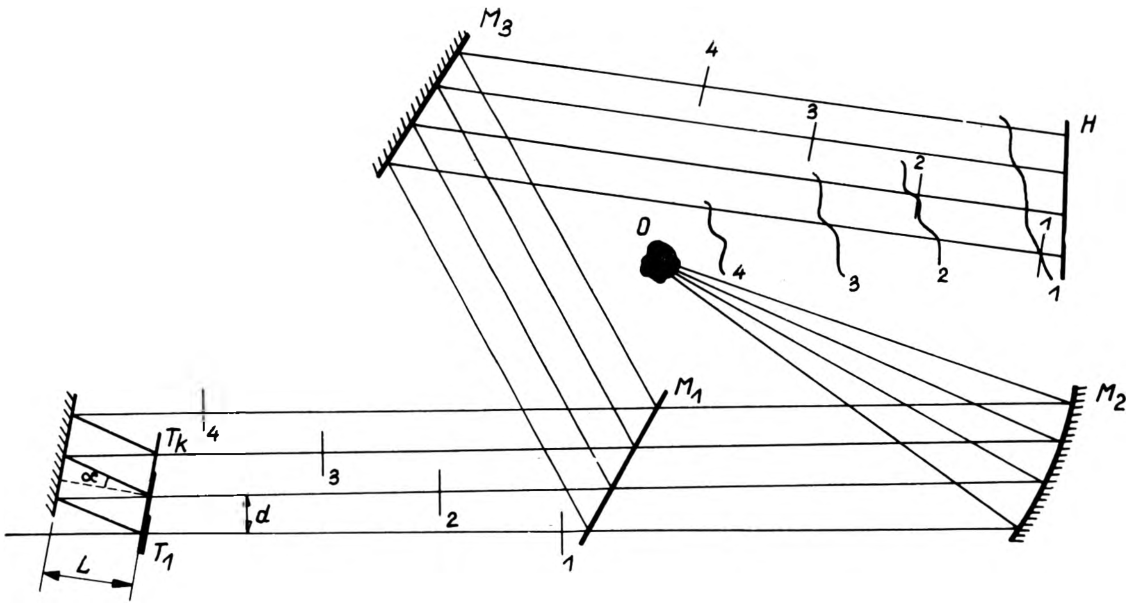

Fig. 1. Holographic coincidence arrangement for obtaining a number of holograms in reflected light
T_1, T_k — semitransparent mirrors, M_1 — semitransparent dividing mirror, M_2 —spherical reflecting mirror, M_3 — plane reflecting mirror, O — object, H — the recording plane

where

τ_i — duration time of the laser pulse,

T — the total time of registration,

τ — wavelength of the laser light,

V_{max} —the maximal expected speed of the tested process development.

Relation (1) is a sampling condition; it means that during τ_i time the state of the tested process can be considered as a static one. This condition is usually satisfied in all photographic methods. Relation (2) is a holographic condition providing to obtain a proper record of interferential field structure.

A single laser pulse comes into a dosing optical delay line which divides it into n pulses separated in time and space. Transmittances of subsequent semitransparent mirrors are determined as follows:

$$T_k = \frac{1}{n-k+1}, \tag{3}$$

where

n — the quantity of holographic records,

k — the number of a consecutive mirror.

Of course

$$k_{max} = n-1. \tag{4}$$

Time and space separation of the pulses getting out from the delay line are determined by

$$\tau_p = \frac{c}{2\cdot L\cdot \cos\alpha} \tag{5}$$

and

$$d = 2\cdot L\cdot \sin\alpha, \tag{6}$$

where

α — the angle of incidence of the original laser pulse at the mirror surfaces.

Following conditions should be satisfied:

a) the time separation condition

$$\tau_i \leqslant \tau_p, \tag{7}$$

b) the space separation condition

$$\varphi_i \leqslant d, \tag{8}$$

where

φ_i — the diameter of the original pulse beam.

A sequence of pulses generated by the delay line is divided by a semitransparent mirror M_1 into two ways: one illuminates the tested object, the other establishes a set of reference waves in the holographic record process. The optical paths of these two ways should be matched to obtain the interference between information waves $u_1, u_2, \ldots, u_n$ and reference waves $u_{01}, u_{02}, \ldots, u_{0n}$ in record plane respectively.

The heart of the space distribution between separate holograms is enclosed in the inherent feature of holografic record process. Indeed, each of the information waves illuminates the total surface of the hologram, but the real holographic record process arises in the coincidence zone of u_k and u_{0k} waves only. During the record process the coincidence zone changes its position jumping from one part of the hologram to another with the period of time equal τ_p. The frequency of the subsequent holographic records corresponding to this period is

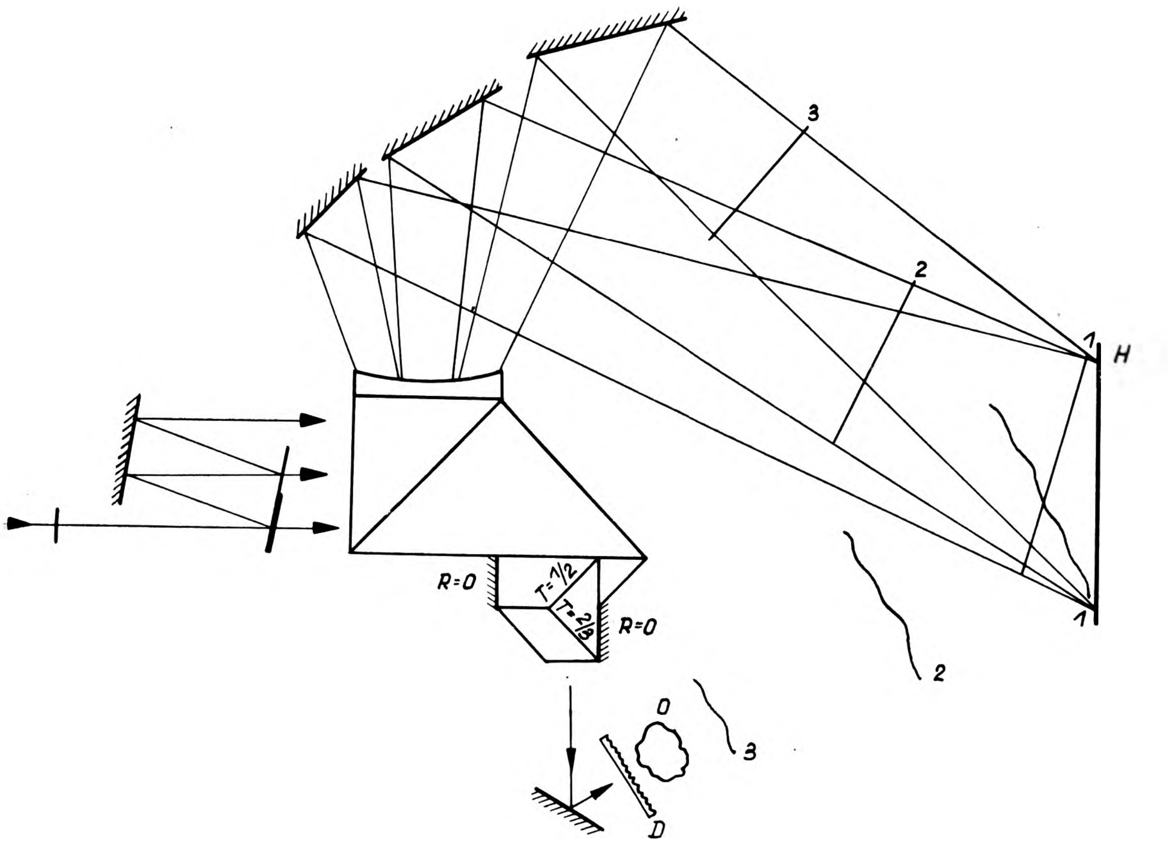

Fig. 2. Holographic coincidence arrangement for obtaining a number of holograms in transmitted light
O — the phase object, D —diffusor, H — the plane recording

$$f = \frac{1}{\tau_p} = \frac{2 \cdot L \cdot \cos\alpha}{c}. \tag{9}$$

Each of the coincidence zones in exposed $n-1$ times by information waves only and once by two interfering waves, i.e. information wave u_k and corresponding to it reference wave u_{0k}. If the amplitude ratio of the u_{0k} and u_k waves is of the order $\sqrt{n}$, it is possible to obtain holograms of sufficient quality.

The above presented idea of obtaining such a series of consecutive holographic records can be applied with success to an investigation of dynamic phase objects. It could be realized as it is done in the arrangement shown in Fig. 1 by illuminating the phase objects at different incidence angles from one side and record of information waves holographic transmitted through the object from the opposite side. There exists, however, a serious disadvantage of such a method: changes of the parallax. Investigation of obtained results could be very difficult in this case. This disadvantage can be eliminated by inserting a special spatial summing device into the path of illuminating pulses, as it is shown in Fig. 2. The arrangement modified in such a way may be intended for investigating the pure phase objects by applying the double exposure method, well known in conventional holographic interferometry. As comes out — from the different directions of separate reference waves in Fig. 2, photo layer as a recording medium is applied malcing the use of the Bragg effect. The space separation between consecutive holograms is accomplished in this way, referring the separate holograms to the incidence angles of reference waves.

It is interesting to compare the register speed of the method proposed by authors and the register speeds of other photographic methods. As mentioned previously, the register speed of the presented method is defined by (9), but the pulse time τ_i is determined by (7). It follows, therefore, that the upper limit of the register speed is determined as the reciprocal of τ_i. If it is a matter of pulse energy sufficient to expose a number of holograms this problem can be considered- as solved if special laser arrangements are used. Of course, other side effects might arise, e.g. high power and energy endurance of optical elements.

Q-modulated lasers can supply pulses of the order of ten nanoseconds. Applying these simple pulse sources it is possible to achieve recording frequencies not more than 10^8 records per second. This value is of the same order as recording frequencies of cameras equipped with electrooptic converters. More complicated laser systems (equipped with electrooptic shutters) are able to supply nanosecond pulses. A substantial improvement occurs when lasers with self-synchronization of modes (SSM) are used. Here, pulse times are of the order of picoseconds. It is possible to achieve register frequencies of the order of 10^{11} records per second if a separate pulse is picked up from a SSM sequence and applied in the multiple holographic arrangement.

It is worth to mention about new kinds of difficulties which must be overcome in this very short pulse holographic technique. The space dimension of a one-picosecond pulse is 0.3 mm and the optical paths in the holographic arrangement should not differ more than a part of this value, e.g. 0.1 mm. The best method of adjusting such interferometers is to adjust them in two steps: 1. roughly by using spectral lamps, 2. exactly by using thermal lamps. The useful surfaces of holograms become smaller for the same reason, sensitivities of photo materials decrease etc.

Authors of this paper hope nevertheless, that this holographic coincidence register method they propose, will be helpful in many high speed register problems.