Study of Thermal Effects in Transparent Objects by Digital Holography Methods

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Abstract. In this article we presented a technique for applying the methods of digital holographic interferometry to analysis the processes, occurring in fluid and solid translucent media under the action o heat sources. The experiments were performed at a small-size stand with the use of a CMOS matrix for recording digital holograms and a computer terminal for data processing. Presented results of investigating the free convection process in a plane water layer and the heat transfer process in a solid, as exemplified by the interaction of radiation with a polymeric recording medium for hologram recording. Features of both processes are examined.

1. Introduction

The study of thermal effects in processes in fluids and solids under the action of external factors is of considerable interest in many scientific and engineering fields [1], as the changes in the temperature of an object lead to those in its optical and physico-mechanical parameters. Investigation of convective fluid flows that accompany most processes in the fluid phase is of great importance in such fields of science and engineering as nanotechnologies, biomedicine, and etc. The study of thermal effects in solids is equally important in research into processes of interaction of radiation with recording media, especially volumetric recording media intended for producing hologram optical elements [2].

2. Experimental setup

In this work we used a stand which is developed for studying transparent objects using methods of digital holographic interferometry (DHI), its optical scheme is given on figure 1. The basis of the development uses the fundamental principles of holographic interferometry [3].

A feature of the experimental stand configuration is setting the unit with the object under study outside the basic interferometry schematic. A considerable elongation of the object beam (as against the reference one) is ensured by great coherence length of the laser radiation used (greater than 10 m).

Placing the object outside the basic optical scheme permits the interferometric studies of the object to be accompanied with other kinds of independent studies (e. g., spectral ones) or the action of external factors on the object to be arranged for.

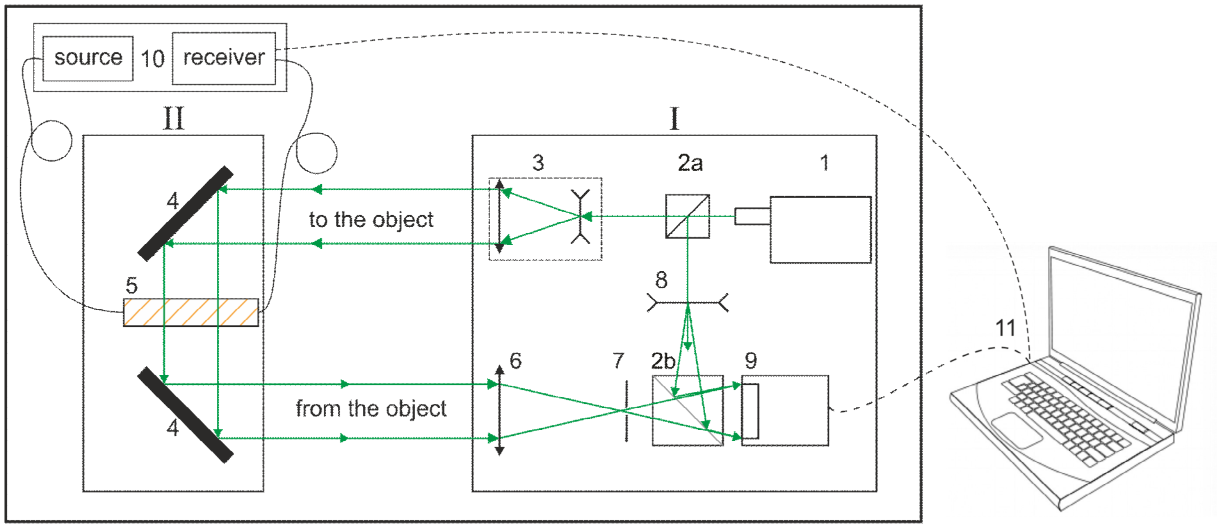

Figure 1. Experimental optical schematic: (1) laser λ = 532 nm, (2) beamsplitters, (3) collimator, (4) mirrors, (5) test object, (6, 8) lenses, (7) diaphragm, (9) videocamera, (10) spectrometer for parallel measurements, (11) computer terminal. I is the interferometer unit, II is the test object unit.

3. Objects of study

To test the developed technique, two processes related to thermal effects were studied: free convection of a fluid under the action of a heart source (A); interaction of radiation with a recording medium, where radiation energy is absorbed and heat propagates from the action region (B).

The object of study in process A is a plane-parallel water layer. Water is an available object suitable as a test object. During the investigation, water was placed in a transparent cell having plane-parallel glass working surfaces, with a heat source inside (tungsten heater in a glass bulb). Wanted convection mode was set by adjusting the heating mode. As the temperature grew, there were no changes in the water layer thickness, the heating was accompanied by variation of the refractive index (in accordance with reference data $dn/dT = -(9.6\cdot10^{-5})$ K^{-1}.[4]

The object of study in process B is the samples of polymeric recording medium «Difphen», developed for recording volume holograms [5]. In the course of action of radiation with a wavelength λ = 473 nm upon a sample, energy is absorbed, which is accompanied with local heating of the sample. This results in changes of the average refractive index of the medium and the geometrical dimensions in the action region. Besides, the changes are oppositely directed: linear thermal expansion, $dl/dT = +(3.5\text{-}6.5\cdot10^{-5})$ K^{-1}, and refractive index, $dn/dT = -(10.5\cdot10^{-5})$ K^{-1}. [6]. Thus, the change of the phase of radiation transmitted through the sample as its temperature varies is due to the difference of coefficients dl/dT и dn/dT and amounts to $d\varphi/dT \approx -(4\div7)10^{-5}$ [6].

4. Experimental procedure and analysis of the results

Processing of the holograms includes a number of stages. To begin with, a hologram series is converted to a series of real-time interferograms. To derive each of the latter, the hologram that characterizes the object state at given instant of time is subtracted from the one that characterizes the initial state of the object (before the start of the action). Such a real-time interferogram is used to find the phase difference for given object state and construct a digital interferogram (figure 2, I) by formulas of [3]. Each digital interferogram represents a distribution of phase difference in the object observation plane, which characterizes object state variation. Further computer processing of digital interferogram allows presenting the experimental results and their sampling in the most convenient form.

Figure 2 shows the results of computer processing of experimental data, obtained in the processes under study: digital interferograms (I) and 3D surface of phase difference variation (phase map) (II).

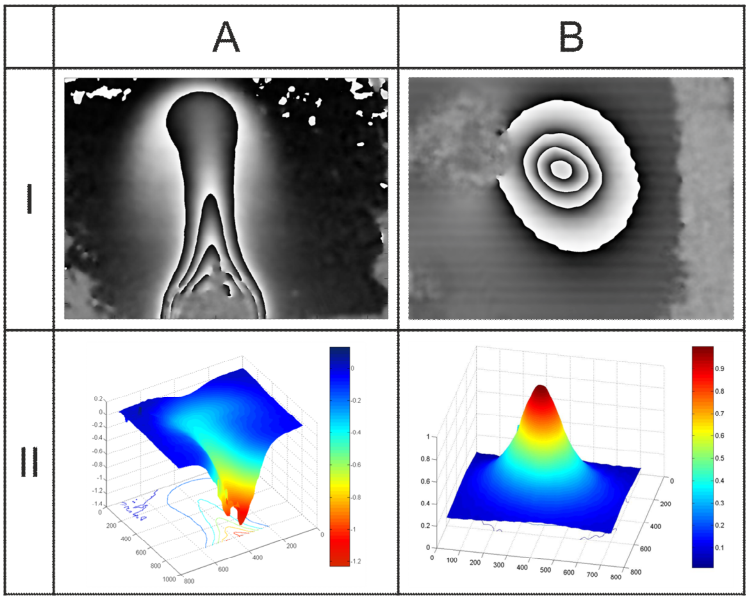

Figure 2. Processing of experimental results: (A) process of free convection in a fluid; (B) process of heat transfer in a solid material. I are digital interferograms, II are 3D surfaces of unwrapped phase difference variation (phase map).

The surface of phase difference variation allows evaluating the temperature field and its changes in the object observation plane. It shall be noted that the calculated surface of phase difference variation (II) indicates the sign of phase variation: with the growing temperature of the sample, the phase advance in process A diminishes, whereas it increases in process B. This disagrees with the values quoted in [6], which were used to estimate the changes in the polymeric base of the sample. Apparently, the PMMA modification used features thermal coefficients differing from tabulated ones, with $dl/dT > dn/dT$ in this case.

5. Conclusion

The presented work implements a technique enabling visual observation and quantitative evaluation of effects due to heat propagation with a source at a local region of the radiation action. The implementation was accomplished on an example of studying the process of free convection in a fluid under the action of a heat source and also a polymeric volume recording medium under the action of radiation, used for hologram recording. The effects of absorbed radiation action were evaluated quantitatively.

The technique can be applied to quantitative evaluation of space-time distribution of the temperature in the object plane within accuracy of tenths of a degree as well as the qualitative assessment of thermal effects on transmissive objects of different parameters.

References

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