Practical works on holographic interferometry and speckle-photography

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ABSTRACT

Brief descriptions of student laboratory works on laser interferometry: "Object deformation analysis by means of holographic interferometry" and "Small displacement investigation by means of double-exposure speckle-photography" are given in the present paper. Deformation bends of metal plates with rough surfaces are investigated in the first work. Arrangements for recording and reconstruction of virtual and real holographic images are presented. Calculation formula and experimental results are given. Small displacement of plane objects with rough surfaces - inclinations and transverse displacements are investigated in the second work. Calculation formula, arrangements for recording double-exposure specklegrams of a displacement and scheme for observations of Young fringes are given.

INTRODUCTION

Laser practical works in Chair of Optics of Saratov State University includes a number of works on interferometric measuring methods. Students of senior courses carry out experimental investigation of coherent properties of thermal and laser radiation sources by means of Newton and Michelson interferometers, determine the profile of the polished surfaces of plates with the help of a prismatic laser interferometer, get acquainted with laser holography and holographic interferometry techniques for measurement of rough surface object deformations, investigate the laser speckle effect and its application with the help of speckle-photography for measurement of scattering objects small displacement, use the Michelson speckle-interferometer for measuring thermal displacements of the electron-gun electrodes of a vacuum device, study the capabilities the laser Mach-Zehnder interferometer for investigation of phase objects.

Only two works on holographic interferometry and speckle-photography from this list are described in this paper. These works are practical confirmation of the lecture courses "Optical Holography" and "Speckle-Interferometry" read by the authors of this paper.

1. Practical work No.1
"OBJECT DEFORMATION ANALYSIS BY MEANS OF HOLOGRAPHIC INTERFEROMETRY"

The aim of the work is to acquaint the student of optical department with physical principles and practical possibilities of holographic interferometry.

Methodical guide includes theoretical and experimental parts. In the first paragraph of theoretical part we try to define holography as a method of waves recording and reconstruction based on intensity distribution recording of interference pattern, which is formed by superposition of object and reference coherent waves. Description of hologram recording main principles and subject wave reconstruction is made. Using the complex amplitude notion the basic holography equation ("equation of holographers") can be derived It describes complex light amplitude distribution in hologram plane with its illumination by reference wave. The methods of virtual and real images observation are described and the properties of holograms are analyzed.

The paragraph "**Holographic interferometry** " concerns with measurement and control methods based on light wave interference, at least one of the wave is reconstructed from hologram. One can distinguish real-time and double-exposure techniques.

In the paragraph "**Fringe forming in holographic interferometry**" the equation for path length difference from identical points on object surface before and after its deformation is derived. The basic equation can be written in the following way:

$$\vec{g}\,(\vec{k}_i + \vec{k}_o) = m\,\lambda, \tag{1.1}$$

where $\vec{g}$ - object point shift vector, $\vec{k}_i$ and $\vec{k}_o$ - illuminating and observing unit vectors, m - the order of interference, λ - light wavelength.

If object surface is deformed so, that every point is shifted in to one direction (for instance, in the case with bending deformations), the Eq.(1.1) is simplified and assumes the form:

$$g\,(\cos\gamma + 1) = m\lambda\ , \tag{1.2}$$

where γ - angle between vectors $\vec{k}_i$ and $\vec{k}_o$. Due to Eq.(1.2) we can define the shift of every point at object surface by angle γ measuring and defining interference fringe order m.

In the paragraph "**Holographic experimental technique**" the basic hologram schemes are described as well as necessary conditions and hologram recording devices: laser application, subject and reference wave optical path equality, vibration isolation, application of recording mediums with high resolution. The scheme for Fresnel hologram recording is suggested as a working one (Fig.1.1).

Experimental part includes the task:
To investigate bending deformation of metal plates under static loads by means of holographic interferometry. Students should obtain holographic interferograms of cantilever bending deformations of a plate and deformation of the plate fixed by its boundaries under directed force. The technical possibilities of holographic set-up allow to realize double-exposure method and real-time method.

Interference fringes parameters are defined with observation of virtual (Fig.1.1) and real images (Fig.1.2) obtained with double-exposure hologram illumination by the beam with small aperture (non-expanded laser beam, Fig.1.2).

Holographic interferogram helps to define the shift of different object points, spread along some axis X, which crosses the center of interference pattern. One also can define x-coordinate and m-order of interference fringe. The calculation of point shift g is made according the Eq.(1.2). Measurement results are tabulated and curve $g = f(x)$ is constructed (Fig.1.3).

2. Practical work No.2
"SMALL DISPLACEMENT INVESTIGATION BY MEANS OF DOUBLE-EXPOSURE SPECKLE-PHOTOGRAPHY"

The aim of the work is to acquaint the student with speckle-affect appeared with illumination of rough surface by laser light. Methodical guide has both theoretical and experimental parts.

The first paragraph of theoretical part **"Speckles in diffusely scattered coherent light field"** briefly analyzes the causes of speckle pattern forming, influence of temporal and spatial coherence of light. The role of optical system resolution when speckle-patterns are observed in real image plane is also discussed. It is noted that average lateral speckle size is inversely proportional to exit angular aperture of optical system.

In the paragraph **"Speckle-pattern application in measurement techniques"** we consider speckle-pattern shift in scattered light field conditioned by object deformation and movement. It is explained that consequent recording of speckle-patterns on photoplate at different moments of time makes possible to record object displacements of micrometer range.

Speckle-pattern mutual shift measurement is carried out by interferential method. If double-exposure specklegram is illuminated by non-expended laser beam according to the scheme at Fig.2.1 in diffractional halo one can observe Young-fringes, oriented perpendicular to speckle-pattern shift.

Fringe space Λ in far-field diffractional region is defined by relation

$$\Lambda = \frac{\lambda L}{d}, \tag{2.1}$$

where L - the distance between specklegram and observation plane, d - speckle-pattern shift in illuminated region of specklegram. Equation (2.1) allows to define speckle shift d according to measured values λ and L. This value is unambiguously related with investigated object surface displacement g .

In the paragraph **"Small slope angles measurement"** it is shown that rough surface slope with angle α causes speckle-pattern shift in the back focal plane of the lens (Fourier-plane) by the value

$$d = f(1 + \cos\gamma)\alpha , \tag{2.2}$$

where γ - the angle of illuminating laser beam incidence. Recording consequently speckle-patterns on photoplate in Fourier-plane before and after surface inclination we can obtain double-exposure specklegram . Illuminating the specklegram according to the scheme at Fig.2.1 one can obtain Young-fringes. By measuring its space Λ we can define the value d , which helps by means of Eq.(2.2) to find the unknown value of a slope angle α.

In the paragraph **"Small lateral shifts measurements"** discussed the measuring techniques of rigid body lateral displacement and in-plane rotation. Suggested techniques differs from that described in the previous paragraph in the fact, that specklegram is recorded in the plane of object real image. The displacement g is defined by Young-fringes observed according to the scheme in Fig.2.1 using Eq.(2.1). Speckle shift d is related with the value g by relation

$$d = \beta g \ , \tag{2.3}$$

where β - lateral image magnification.

Experimental part includes two tasks:

1. To define slope angle of diffusely scattering plate;
2. To define small lateral displacement of diffusely scattering plate.

According to task No.1 the optical scheme is arranged as it is shown in Fig.2.2. Speckle-pattern is double-recorded in Fourier-plane on photoplate with high resolution before and after object small inclination. The value of a slope should be between

$$\frac{(1+\cos\gamma)}{D}\lambda < \alpha < \frac{w}{10(1+\cos\gamma)f} \tag{2.4}$$

where D and f - corresponding aperture diameter and focus of the recording lens (Fig.2.2), w - cross section diameter of non-expended laser beam illuminating the specklegram (Fig.2.1). In our case slope angle is equal to 10^{-3} radian.

In the task No.2 optical scheme is arranged according to Fig.2.3. Object rough surface and photoplate are set in conjugated planes (object and image planes), correspondingly at distances a and b from the lens. Young-fringes can be obtained accordingly Fig.2.1 and the space Λ of fringes and distances a and b for magnification β definition, first d should be calculated, then g with the help of Eq.(2.3)

CONCLUSIONS

The main attention is paid to the measuring capabilities of these methods in the given laboratory works on holographic interferometry and speckle-photography. The fringe formation is considered from simplified positions without taking into account speckle modulation of interfering light fields. The interference of speckle-modulated waves take place in many methods of holographic and laser interferometry. In this connection the understanding of physical features of speckle-field interferometry is of great methodological importance. At present we carry out the practical work "Speckle-Field Interference" It is supposed in this work to study the interference of nonidentical (uncorrelated) and identical (correlated) speckle-fields on the basis of the Michelson interferometer and investigate the effect of fringe localization and their visibility dependence on the mutual displacement of interfering identical speckle-fields.

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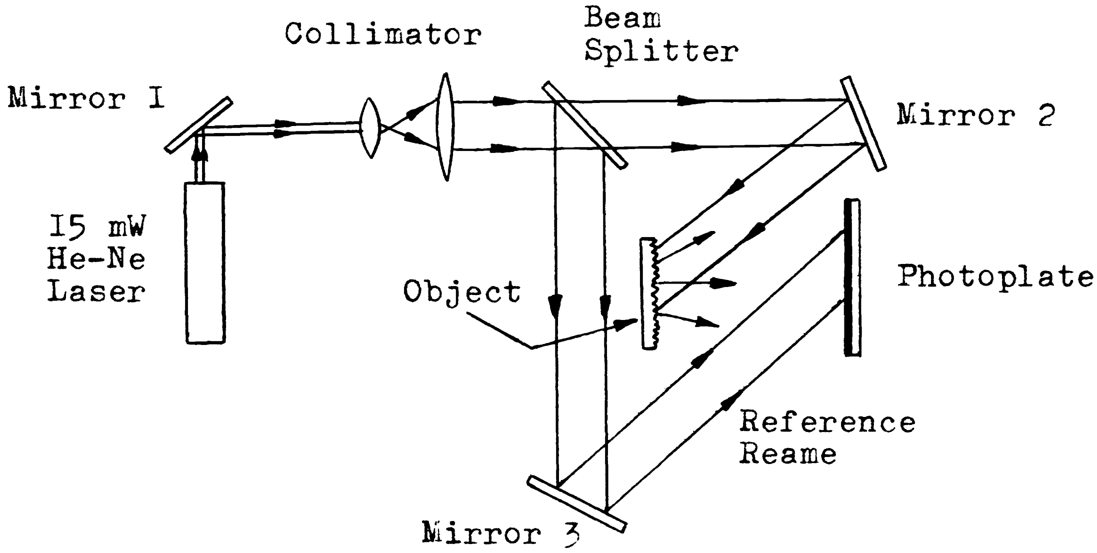

Fig.1.1. Optical scheme of hologram recording and holographic interference fringes observing.

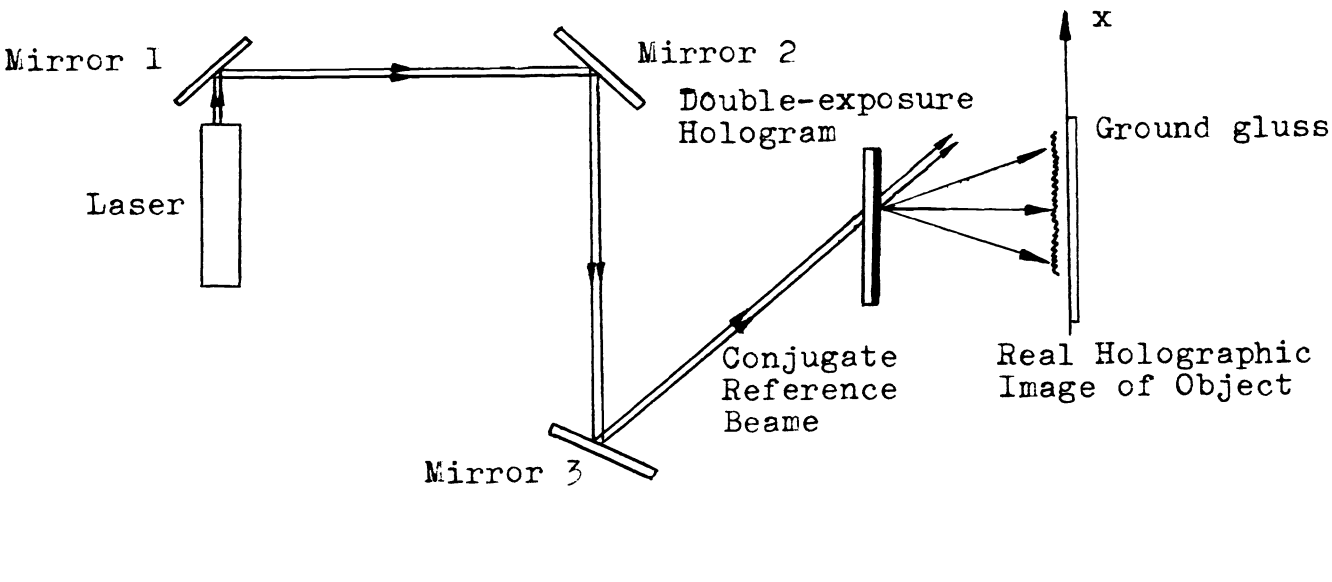

Fig.1.2. Optical scheme for interference fringes observations on real holographic image of an object.

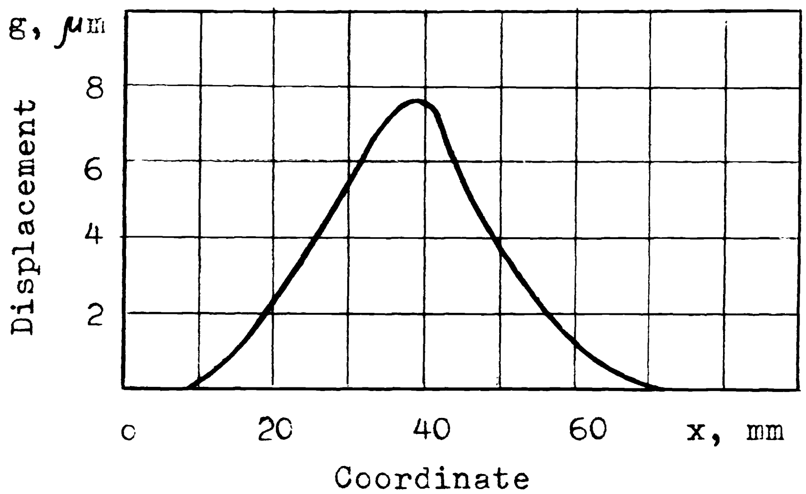

Fig.1.3. Curve of plate bending deformation appeared under directed force.

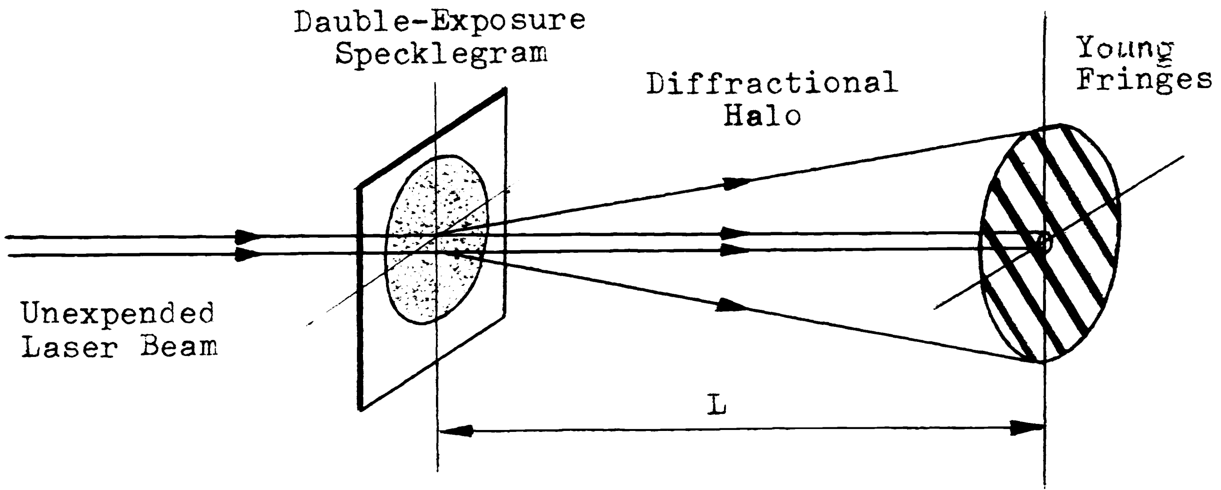

Fig.2.1. The arrangement for Young-fringes observation in double-exposure speckle-photography.

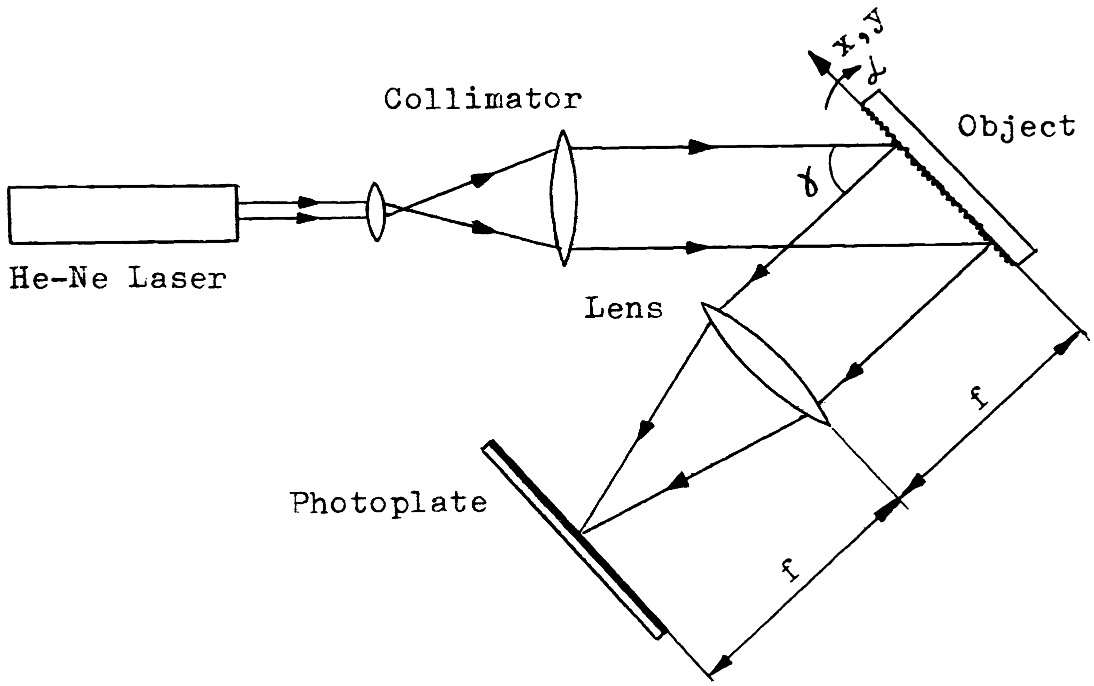

Fig.2.2. Optical scheme of object slope double-exposure specklegram recording.

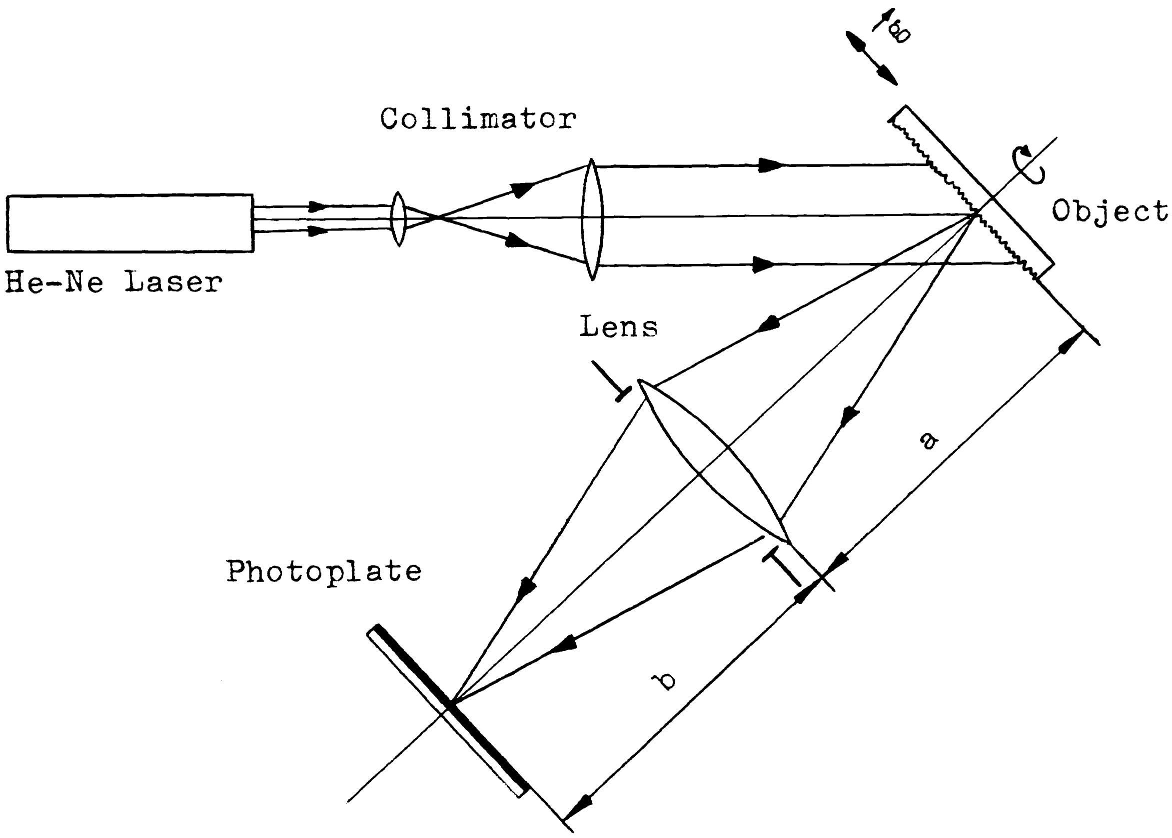

Fig.2.3. Optical scheme for double-exposure specklegram recording of lateral object displacement.