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Digital speckle photography with the ring aperture diaphragm

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Abstract

In this paper theoretical and the experimental studies of application of optical systems with the ring apertures diaphragm in double-exposure speckle photography at the registration of the specklegram are presented. The application of optical systems with the ring apertures allows to increase sensitivity and to expand effective range at measurement of displacements by the double-exposure speckle photography. Theoretical estimates of the expansion of the range of measured displacements are presented. Experimental results of the analysis of interference patterns reconstructed by Young's method with double-exposure speckle photography confirming theoretical calculations are presented.

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Keywords: Speckle photography; speckle-interferometry; digital speckle photography; Young's method; diffraction halo; the spatial spectrum; measurement of displacements

1. Introduction

The high potential of modern numerical methods for analyzing the stress-strain state made it possible to deduce the experiment to a new qualitative level. Thus, it became possible to set the problem of experimental research more correctly, and also to interpret its results. Nevertheless, experimental methods remain the main criterion for the validity of existing mathematical models, despite the great achievements in the field of the development of computer

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technologies and mathematical methods of numerical modeling, which allow solving a wide class of problems of mechanics [1,2]. A special place is occupied by optical methods, since they possess such an important property as contactless, which in turn leads to an increase in the accuracy and reliability of obtained results. The high metrological characteristics are possessed by coherent methods, such as holographic interferometry, speckle interferometry, speckle photography and the like, and due to the large amount of experimental data, these methods do not have any other alternatives [3].

Due to low requirements to the stability of the optical system (in comparison with holographic interferometry), speckle interferometry and speckle photography is widely used in industry [3-7].

The sensitivity of speckle interferometry and speckle photography to determining the amount of displacements depends on the size of the speckle structure, which is determined by the parameters of the used optical system when recording a subjective speckle structure, i.e. numerical aperture of the optical system. On the one hand, an increase of the numerical aperture of the optical system leads to a decrease of the size of the recorded speckle structure and, consequently, to an increase in the sensitivity of speckle interferometry and speckle photography. However, on the other hand, an increase of the numerical aperture of the optical system leads to the requirement of using high-quality optics, since such parameters as aberrations of the optical system begin to affect significantly, which lead to distortion of the recorded information. Theoretical and experimental investigations of operation of optical instruments, such as reflecting telescopes and mirror lenses, have shown, that the availability of a ring aperture allows to increase their resolution [8,9]. Therefore, the aforementioned fact represents theoretical and experimental interest for research applications of the ring aperture in the speckle interferometry and speckle photography. It should also be noted that the proposed application of ring apertures can be used in the design of optical systems of hyperspectral equipments [10,11].

It should be noted that the range of controlled displacements for speckle interferometry is in the range 0.3-6.3 μm, and for speckle photography 0.001-1 mm. Thus, the application of both methods makes it possible to extend the metrological characteristics of the integrated measurement system on the basis of these methods.

In this paper theoretical and the experimental studies of application of optical systems with the ring apertures in double-exposure speckle photography at the registration of the specklegram are presented. The application of optical systems with the ring apertures allows to increase sensitivity and to expand range measure at measurement of displacements by the double-exposure speckle photography.

2. Vander Lugt's method

To describe the propagation of a signal through an optical system, we use the method proposed by Vander Lugt [12]. This method is based on the fact that the Fresnel-Kirchhoff theory is considered in the geometric optics approximation and is introduced the function that makes it possible to simplify the theoretical calculations at calculating the propagation of an optical signal in optical systems. The function has the following kind:

$$\Psi(x, y, D) = e^{-\frac{i\pi D}{\lambda}\left(x^2+y^2\right)}, \tag{1}$$

where $D = 1/d$, and d is the distance from the x,y plane to the plane which the phase value is determined, and λ is the wavelength of the laser radiation.

We list some properties of the function $\Psi\ (x,y,p)$:

$$\Psi(x, y, p) = \Psi^*(x, y, -p), \tag{2}$$

$$\Psi(-x, -y, p) = \Psi(x, y, p), \tag{3}$$

$$\Psi(x, y, p_1) \cdot \Psi(x, y, p_2) = \Psi(x, y, p_1 + p_2), \tag{4}$$