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Photopolymer diffractive optical elements in electronic speckle pattern shearing interferometry

Emilia Mihaylova[a,*], Izabela Naydenova[a], Barry Duignan[b], Suzanne Martin[a], Vincent Toal[a]

[a]*Centre for Industrial and Engineering Optics, Dublin Institute of Technology, Kevin Street, Dublin 8, Ireland*
[b]*Faculty of Engineering, Dublin Institute of Technology, Bolton Street, Dublin 1, Ireland*

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Abstract

In this paper we present an electronic speckle pattern shearing interferometer using a photopolymer diffractive optical element in the form of a holographic grating, in combination with a ground glass to shear the images. The sheared images on the ground glass are further imaged onto a CCD camera. The distance between the grating and the ground glass can be used to control the shear and to vary the sensitivity of the system. The direction of sensitivity is easily controlled by rotation of the diffraction grating around its normal.

Introducing photopolymer holographic gratings in ESPSI gives the advantage of using high aperture optical elements at relatively low cost. The fact that the diffractive optical element is a photopolymer layer on glass substrate with thickness of 2 mm makes for a compact optical system.

The system was successfully used for detection of the resonant frequencies of a vibrating object.

Most of the published work on vibration analysis is analytical. Very few experimental results are available in the literature. The well known laser Doppler vibrometers (LDV) and accelerometers used for modal analysis are pointwise measurement techniques, although multipoint LDV is available at significant cost.

Electronic speckle pattern techniques suitable for experimental detection of the resonant frequencies of vibrating objects are very promising for vibration analysis because they are whole field and non-contact.

*Corresponding author.
E-mail address: emilia.mihaylova@dit.ie (E. Mihaylova).

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A finite element model is developed for prediction of the vibration modes of the object under test. Detection of vibrational modes of aluminium diaphragm is demonstrated and compared with the theoretical model. The results obtained are very promising for future application of ESPSI systems with HOEs, for modal analysis. A significant advantage of shearography over electronic speckle pattern interferometry is that ESPSI is relatively insensitive to external disturbances. Another advantage of the proposed system is that it could be easily converted to a phase-shifting electronic speckle shearing interferometer.

Keywords: ESPSI; Shearing interferometry; Holographic gratings; Modal analysis; Vibrations; FEA; Phase-shifting

1. Introduction

Electronic speckle pattern shearing interferometry (ESPSI) is an optical technique that enables full-field and non-contact direct measurements of displacement derivatives to be made [1–8]. A common method for generating two sheared images of the object in ESPSI systems is to use a Michelson interferometric optical set-up. The shear is introduced and controlled by tilting one of the mirrors.

The idea of using a holographic grating for shearing of the two images in speckle shearing interferometry is not new. Some early non-electronic systems used photographic gratings [5–7], but the use of CCD cameras enables observation of real-time fringe formation [8,9]. Recently there has been an increasing interest in the application of shearography for modal analysis of vibrating objects. New interferometric systems are of interest for engineering and industrial applications.

We present the use of photopolymer holographic grating in a ESPSI system for modal analysis. Self-processing acrylamide based photopolymer [10] is used as a recording medium for recording holographic gratings. The optimized photopolymer material gives good diffraction efficiencies up to 94% for an exposure of 80 mJ/cm^2 and it performs well in the transmission mode of hologram recording. The holographic grating is used in combination of a ground glass to shear the images and to control the size of the shear.

2. Theory

When two light waves interfere, the following equation [11] relates their relative phase Φ at a point to their relative geometrical path difference L:

$$\Phi = \frac{2\pi}{\lambda} nL - \beta, \tag{1}$$

where λ is the wavelength of the laser light, n is the refractive index of the medium through which the laser light is transmitted, and β is a constant phase. The change in the relative phase $\Delta = \delta\Phi$ or phase change, which manifests as visible fringes, can be