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Whole Field Out-of-plane Vibration Analysis with a HOE-based ESPI System

Emilia Mihaylova
Technological University Dublin, emilia.mihaylova@tudublin.ie

Viswanath Bavigadda
Technological University Dublin, viswanath.bavigadda@student.dit.ie

Raghavendra Jallapuram
Technological University Dublin, mrutic@gmail.com

See next page for additional authors

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Authors
Emilia Mihaylova, Viswanath Bavigadda, Raghavendra Jallapuram, and Vincent Toal

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with a HOE-based ESPI system

Emilia Mihaylova*, Viswanath Bavigadda, Raghavendra Jallapuram, Vincent Toal

Centre for Industrial and Engineering Optics, Dublin Institute of Technology,
Kevin Street, Dublin 8, Ireland
*Corresponding author: ***emilia.mihaylova@dit.ie***
tel: +35314024702; fax: + 35314024988

ABSTRACT

Electronic speckle pattern interferometry (ESPI) is a full-field measurement technique, capable of displaying vibrational mode shapes. A simple optical set-up for an ESPI system using a holographic optical element (HOE) is presented. The HOE is designed to create a speckled reference beam in the interferometer. A partially reflective glass plate provides illumination of the object along the normal to its surface, ensuring that the system is sensitive only to out-of-plane displacement of the object. It is demonstrated that the HOE-based system can be used for vibration measurements. Phase shifting can be implemented for fringe analysis. A big advantage of the system is its simplicity. It requires a small number of components: a coherent light source, a holographic optical element, a glass plate and a CCD camera. Introducing holographic optical elements in ESPI gives the advantage of large aperture optical elements at relatively low cost.

Keywords: ESPI, interferometry, mode analysis, vibrations, holographic optical elements, HOE

1. INTRODUCTION

Electronic speckle pattern interferometry (ESPI) was first proposed by Butters and Leendertz1[1] for investigation of out-of-plane vibrations. In ESPI[2] a speckle pattern is formed by illuminating the surface of the object to be tested with laser light. This speckle pattern is imaged onto a CCD array and allowed to interfere with a reference wave, which may or may not be speckled. The resultant speckle interference pattern is transferred to a frame grabber on board a computer, saved in memory, and displayed on a monitor. When the object has been deformed or displaced, the resultant speckle pattern changes owing to the change in path difference between the wave front from the surface and the reference wave. The second resultant speckle pattern is transferred to the computer and subtracted from the stored pattern and the result rectified. The resulting interferogram is displayed on the monitor as a pattern of dark and bright fringes, called correlation fringes. In real time it is possible to grab frames continuously while a deformation is occurring and then subtract them in succession from the first speckle pattern. This process makes it possible to observe the real-time formation and the progressive changes of the fringe pattern related to the deformation of the surface.
Electronic speckle pattern interferometry has been widely used as a technique for experimental vibration analysis since the 1980s[3]. Recently there has been an increasing interest in the application of ESPI for measuring dynamic deformations such as vibrations in automotive components[4-7]. The recorded ESPI fringes are the contours of constant vibrational amplitude. Based on the fact that clear fringe patterns will appear only at resonant frequencies, the corresponding mode shapes can be obtained experimentally. For these reasons, ESPI has become a powerful technique for research and for many engineering applications and has great potential for modal analysis.

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2. PRINCIPLE

A simple optical set-up for an ESPI system using holographic optical element (HOE) is presented. A reflection holographic optical element (RHOE) creates a speckled reference beam in the interferometer. RHOEs were recorded on red sensitized silver halide emulsions PFG-03M (Geola) on glass substrate (63 mm x 63 mm), using the Denysiuk method (Fig. 1). The object used to record the RHOE is a flat diffusely reflecting surface so that, on reconstruction, a diffuse beam of laser light is produced to act as a reference beam in the interferometer.

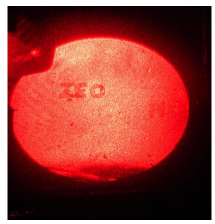

Fig. 1. A typical reconstructed image from a reflection hologram. The diffraction efficiency (defined as the ratio of diffracted light intensity to incident) is above 50%.

The illumination of the test object along the normal to its surface is provided by a partially reflective glass plate (Fig. 2). The reflection coefficient of the coating was chosen to be 0.7. The combination of the partially reflective glass plate and the RHOE, having 50% diffraction efficiency, produces two interfering beams with equal intensities and the fringe contrast is very good. The intensities of the beams can be equalized by slight rotation of the RHOE. The real time interference patterns are captured and subsequently processed using EspiTest software[8].

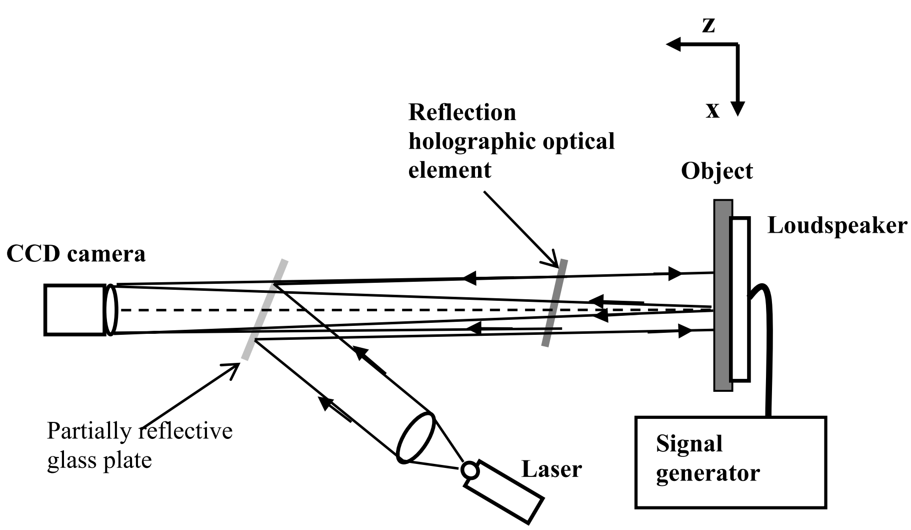

Fig. 2. ESPI system with a holographic optical element and a partially reflective glass plate

The ESPI system with a RHOE and a partially reflective glass plate system can also be used as phase-shifting interferometer. For that purpose the RHOE or the glass plate is mounted on a piezoelectric transducer (PZT). This phase-shifter allows the introduction of a known phase shift and it is useful for vibration studies.

3. EXPERIMENTAL RESULTS AND DISCUSSION

The HOE-base ESPI system was used in studying the vibration modes of an edge clamped aluminium diaphragm (40 mm diameter, 0.5 mm thick). The diaphragm was excited at different frequencies in the range from 2400 Hz to 7600 Hz by a loudspeaker placed behind it. The loudspeaker is driven by a sinusoidal signal of amplitude varying between 1V and 5 V and different frequencies. Time-averaged ESPI was used for all vibration studies.

An important factor for the performance of the HOE-based ESPI system is the angular selectivity of the RHOE, which provides the reference beam. This requires careful adjustment of the RHOE in the optical set-up in order to have high quality ESPI fringes. Good quality speckle interferograms corresponding to various vibrational modes were recorded (Fig. 3 and Fig. 4). There was no need to use any filter to reduce the speckle noise in the images.

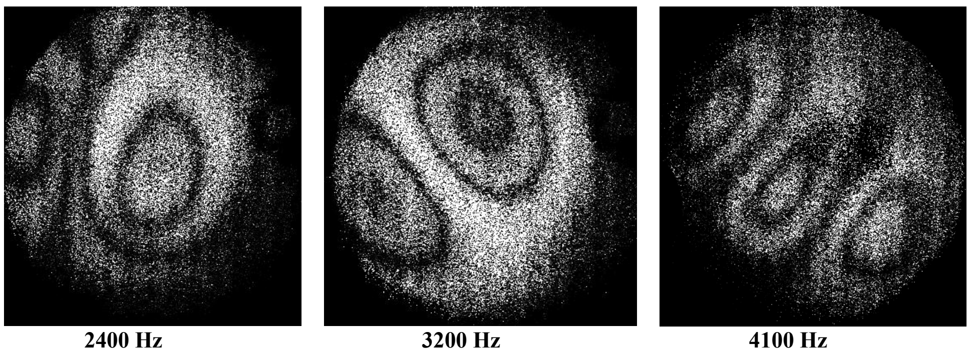

Fig. 3. ESPI vibration modes of an aluminium diaphragm. The amplitude of the sinusoidal signal driving the loudspeaker is 1 V. The field of view is 40 mm x 40 mm.

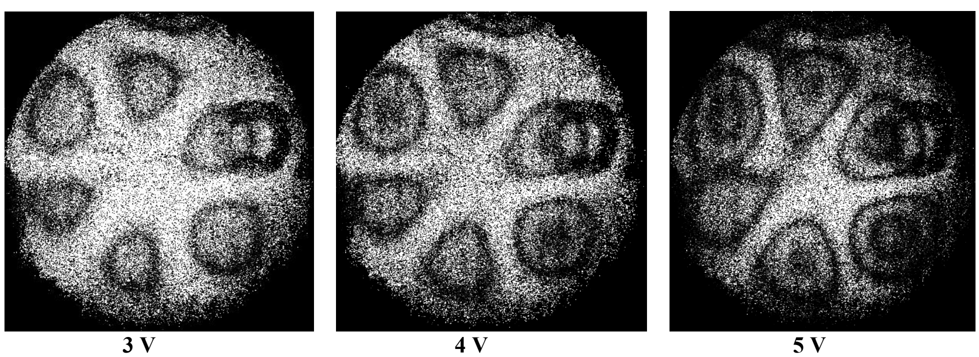

Fig. 4. ESPI vibration modes of an aluminium diaphragm recorded at frequency 7600 Hz. The amplitude of the sinusoidal signal driving the loudspeaker is 1 V. The field of view is 40 mm x 40 mm.

4. CONCLUSIONS

The ESPI system with a reflection HOE and a glass plate is simple and compact. It is demonstrated that a HOE-based ESPI system can be used for whole field out-of-plane vibration measurements. The results obtained are promising for future applications of the systems for modal analysis. The shapes of the resonant modes can be found in real time by varying the frequency and amplitude of the excitation signal. Introducing holographic gratings in ESPI gives the advantage of using high aperture optical elements at relatively low cost.

Acknowledgments

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