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Short note

Three-dimensional phase-shifting electronic speckle pattern interferometry based on a non-cube beam-splitter

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ABSTRACT

A novel Cube Beam-Splitter, called Non-Cube Beam-Splitter (NCBS), is used for three-dimensional phase-shift Electronic Speckle Pattern Interferometry (ESPI). By using the NCBS lights from a tested object and lights from a reference surface can be combined and then interfere each other on a CCD camera when a laser beam illuminates the test object and the reference surface simultaneously. When three laser beams illuminate the test object at different incident angles respectively before and after deformation, three interference fringe patterns are formed. Then three phase maps corresponding to three lasers can be calculated by using phase-shift, by which three displacement components are completed. The principle of the method is presented and proved by a typical three-point bending experiment. Experimental results are offered.

1. Introduction

Electronic speckle pattern interferometry (ESPI), a widely employed technique for measuring static and dynamic deformations, offers many advantages to experimental mechanics, such as whole-field coverage, speed, non-contact, and sensitivity [1]. Applications range from simple nondestructive inspection to sophisticated three dimensional measurement. The measurement of a surface's displacements in three dimensions is often required because the deformation of an object is usually three dimensional. There have been many techniques reported to measure the three dimensional displacement of an object. Optical fibers are useful in illumination with different sensitivity vectors [2]. Using three object beams and one reference beam, three orthogonal components of displacement can also be measured by Fourier transform method [3]. By using three different wavelengths of visible light three-dimensional measurement with FTM is then achieved, in which three mirrors are used to produce fringe carrier patterns to modulate three deformed fringe patterns respectively [4]. For determining the absolute phase without additional measurements, four illuminations are used [5]. Different from these methods of three illumination beams, three sensors are used [6]. Either interferometers with three illuminations or interferometers with three sensors provide lower sensitivity in both in-plane and out-of-plane displacement components [7]. In order to increase the sensitivity of the displacement components, 3-D evaluation of deformations are performed by the combination of the in-plane and out-of plane ESPI interferometers [7,8]. The advantage of the combination method is that it can obtain three components of displacement directly without computation. But it is too complicated in optical arrangement. One set of out-of plane ESPI interferometer and two sets of in-plane ESPI interferometers are combined. The complicated optical

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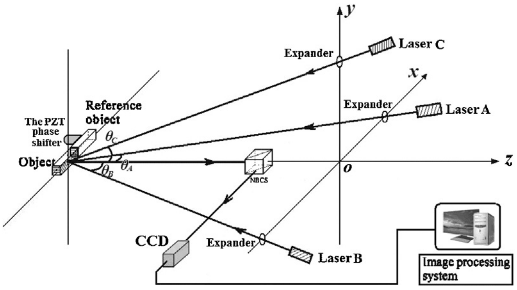

Fig. 1. The setup of 3D-ESPI with NCBS.

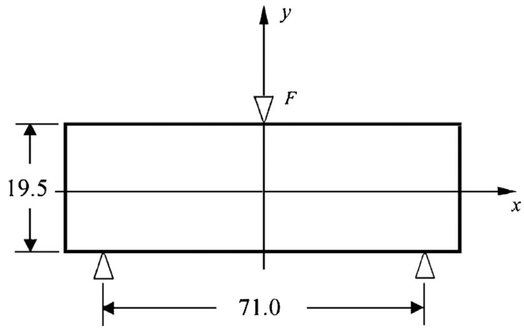

Fig. 2. Schematic of the sample and the loading.

arrangement affects the measurement precision a lot. Give attention to the sensitivity of the displacement components and the simplicity of the optical setup, two sets of in-plane ESPI interferometers are combined with phase calculation [9].

Now a new three dimensional measurement with a new designed prism, called Non-Cube Beam-Splitter (NCBS), is presented. With the use of the NCBS, the reference beam (i.e., light scattered from the reference surface) and the object beam (i.e., light scattered from the test object) are combined [10]. Because the reference beam and the object beam are approximatively coaxial, it is less affected by surroundings and not requires another reference beam. Then the optical setup of 3-D ESPI is simple.

2. The setup of 3D ESPI with NCBS

The 3-D ESPI setup is shown in Fig. 1. A reference surface is fixed, adjacent to the test object. They are illuminated simultaneously by three expanded laser beams. Three lasers A, B and C, whose power and intensity are nearly equal, are fixed in the x and y axes direction and illuminate the tested object and the reference surface at the angleθ_A, θ_B and θ_C respectively. The PZT phase shifter is attached to the reference surface behind. The NCBS is placed at the normal of the tested object in the z axis direction. The reference beam (i.e., light scattered from the reference surface) and the object beam (i.e., light scattered from the test object) after passing through the NCBS are combined, resulting in optical interference. The optical interference between the reference and object beams results in the formation of a speckle pattern to be recorded with a CCD camera. The angle between the reference beam and the object beam is just the separation angle of the NCBS.

Consider a point $P(x, y)$ on the surface of the object and assume that it has a displacement, $\vec{d}(x, y) = u(x, y)\vec{i} + v(x, y)\vec{j} + w(x, y)\vec{k}$ after a deformation. u, v, and w represent the components of displacement in the x, y, and z directions, respectively. The relationship between the phase change,$\Delta\phi(x, y)$, and the deformation is given by

$$\Delta\phi(x, y) = \frac{2\pi}{\lambda}[\vec{d}(x, y)\cdot\vec{s}] \quad ,(1)$$

where $\vec{s}$ is the sensitivity vector of the speckle interferogram obtained in the plane (x, y), λ is the wavelength of the applied laser. When three lasers illustrated in Fig. 2 illuminate the object respectively, the phase change can be expressed by

$$\begin{pmatrix} \Delta\phi_A \\ \Delta\phi_B \\ \Delta\phi_C \end{pmatrix} = \frac{2\pi}{\lambda}\begin{pmatrix} -\sin\theta_A & 0 & 1+\cos\theta_A \\ \sin\theta_B & 0 & 1+\cos\theta_B \\ 0 & \sin\theta_C & 1+\cos\theta_C \end{pmatrix}\begin{pmatrix} u \\ v \\ w \end{pmatrix} \quad (2)$$

where $\Delta\phi_i \quad (i = A, B, C)$represents the phase change obtained when three lasers illuminate the test object at the incident angle $\theta_i \quad (i = A, B, C)$ respectively.