In-plane Sensitive Electronic Speckle Pattern Interferometer using a Diffractive Holographic Optical Element

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In-plane sensitive electronic speckle pattern interferometer using a diffractive holographic optical element

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We describe a student project in electronic speckle pattern interferometry. The project includes holographic recording of diffraction gratings in thick self-processing photopolymer layers made from off-the-shelf chemicals. The gratings are employed in a simple electronic speckle pattern interferometer to measure in-plane rotation. © 2011 American Association of Physics Teachers.

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I. INTRODUCTION

Electronic speckle pattern interferometry is a simple optical technique for measuring small displacements of optically rough surfaces. The technique is well known and easy to implement using simple optical components. Speckle pattern interferometry using a photographic method was first reported by Archbold et al. and further developed by Butters and Leendertz. Electronic speckle pattern interferometry has found many applications in nondestructive evaluation, mechanical stress analysis, and vibration analysis.

In electronic speckle pattern interferometry the surface of an object is illuminated by laser light producing a speckled object beam which interferes with a coherent reference beam. The resulting speckle interferogram is imaged on a CCD camera, transferred to a computer, and saved in memory. When the surface is displaced, the speckle interferogram is changed due to the change in path length difference between the object and reference beams. This second interferogram is subtracted pixel by pixel from the first. The result is rectified and displayed as a set of bright and dark fringes according to Eq. 1.

\[ I = I_1 + I_2 + 2 \sqrt{I_1 I_2} \cos \phi, \]  

where \( I_1 \) and \( I_2 \) are the intensities of the two beams and \( \phi \) is the phase difference between them.

When a point on the object undergoes a small in-plane displacement, \( d \), in the plane of the illuminating beams, the phase difference between them is altered by \( \Delta \phi \), which from Fig. 1(b) is

\[ \Delta \phi = \frac{4 \pi}{\lambda} d \sin \theta, \]

and the intensity in Eq. (1) becomes

\[ I' = I_1 + I_2 + 2 \sqrt{I_1 I_2} \cos(\phi + \Delta \phi). \]

The difference of Eqs. (1) and (3) gives

\[ |I - I'| = 4 \sqrt{I_1 I_2} \sin \left( \phi + \frac{\Delta \phi}{2} \right) \sin \left( \frac{\Delta \phi}{2} \right), \]

which represents a fringe pattern having intensity maxima at \( \Delta \phi = (2p+1)\pi \), with \( p \) as an integer, and minima at \( \Delta \phi = 2p\pi \), the fringes being modulated by speckle.

If \( d \) is spatially dependent, the phase change gives rise to bright and dark fringes according to Eq. (4). From Eq. (2) the in-plane displacement undergone by a given point is

\[ d = \frac{n \lambda}{2 \sin \theta}, \]

where \( n \) is the number of fringes passing through the point during the displacement \( d \).

The simplest, spatially dependent, in-plane displacement is the rotation of a flat circular disk in the \( x-y \) plane as shown in Fig. 1(c). The wave vectors of the illuminating beams lie in the \( x-z \) plane. If the disk rotates through an angle \( \delta \alpha \), a point with polar coordinates \( r \), \( \alpha \) is displaced by \( r \delta \alpha \cos \alpha \) in
polymer solution was deposited on a 63×63 mm² clear glass leveled plate and allowed to dry at ambient temperature, which normally takes about 12 h. The thickness of the dry layer, measured using a white light surface profilometer, was 100 μm. A micrometer gauge can also be used, with care, for thickness measurements.

Figure 2 shows the optical setup used to record the diffractive holographic optical elements. The components were mounted on a mechanically isolated optical table. An optical breadboard supported on partially inflated inner tubes (motor scooter tires) serves very well. The exposure was adjusted to be around 50 mJ cm⁻² until zero and first order diffracted beams of equal intensity were obtained from the recorded gratings. A suitable angle, 2θ, between the recording beams is obtained from Eq. (6). For example, an angular rotation of the disk by 1.0 mrad results in ten electronic speckle pattern interferometry fringes in a field of view of 1 cm when using a diffractive holographic optical element recorded at 532 nm with an angle of 30° between the beams in Fig. 2.

The circular disk was rotated in plane by a motor driven micrometer. The angle of rotation was independently measured by the displacement of a He-Ne laser reflected onto the wall of the laboratory from a small plane mirror attached to the rim of the disk. The field of view was measured on the display by placing a ruler against the disk.

### IV. RESULTS AND DISCUSSION

Figure 3 shows some of the electronic speckle pattern interferometry fringe patterns we obtained. The fringe contrast was very good initially, although it became difficult to count fringes with complete confidence when about 15 had accumu-

![Fig. 2. Diffractive holographic optical element recording.](image)

![Fig. 3. Electronic speckle pattern interferometry fringe patterns for in-plane rotations of (a) 1.1, (b) 0.80, (c) 0.69, and (d) 0.58 mrad. The field of view is 9 mm. The dark area is a bolt securing the disk to the rotator.](images)
An in-plane sensitive electronic speckle pattern interferometer was implemented using a diffractive holographic optical element that was holographically recorded in a photopolymer. Fringes of good contrast were obtained and used in the measurement of in-plane rotation of a disk. A diffractive holographic optical element can be easily substituted for one with the grating spacing suited to the estimated magnitude of the rotation to be measured. The project can be extended to the measurement of in-plane strains.

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