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HOE-based ESPI Systems

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ABSTRACT

Electronic speckle pattern interferometry (ESPI) is a full-field measurement technique, capable of displaying vibrational mode shapes. Two electronic speckle pattern interferometers using reflection holographic optical elements (RHOEs) are presented. In the first ESPI system the RHOE is designed to create the speckled reference beam. 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.

In the second ESPI system a reflection holographic optical element of a flat diffusely reflecting surface serves a dual purpose. On reconstruction, a diffuse beam of laser light is produced to act as a reference beam in the ESPI system. Undiffracted light passing through the RHOE serves to illuminate the object. This system is not completely insensitive to in-plane displacement but the illumination and observation directions can be made nearly collinear.

The systems are compared in terms of flexibility in their adjustment, sensitivity, suitability and limitations for different applications.

The introduction of holographic optical elements in ESPSI systems gives the advantage of using high aperture optical elements at relatively low cost. Both systems are suitable for out-of-plane vibration studies. The results obtained are promising for future applications of RHOEs in alternative laser Doppler vibrometry systems.

Keywords: *Laser Doppler vibrometry, LDV, vibrations, holographic optical elements, HOE, ESPI, interferometry, mode analysis*

1. INTRODUCTION

Electronic speckle-pattern interferometry (ESPI) is a widely used tool for non-destructive evaluation and material properties analysis[1-5]. ESPI was originally developed for vibration analysis[1]. It was then successfully extended to static displacement measurements, heterodyning and stroboscopic techniques to recover the vibrational phase information and surface profile measurement. Advances in electronics and computing have made it a powerful tool for laboratory and industrial use[2-5].

Holographic optical elements (HOEs) can be used as an alternative to expensive conventional optical elements. The basic idea in the HOE based ESPI systems presented here is the use of a speckle reference wave, which is stored in a holographic optical element. Incorporating reflection HOE in an ESPI system simplifies the optical set-up and its alignment. We suggest new applications of HOEs in two ESPI optical set-ups to provide the reference beam. Introducing HOEs in ESPI gives the advantage of using high aperture optical elements at relatively low price and makes the system compact.

2. THEORY

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 interference pattern changes owing to the change in path difference between the wave front from the surface and the reference wave. The second resultant speckle interference 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 interference 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. ESPI can be used to detect the deformations in the sub-micrometer range, of the surface of a stressed object. Depending on the design of the interferometer, in-plane sensitivity or out-of-plane sensitivity can be obtained.

3. EXPERIMENT

3.1. Recording reflection HOEs

Reflection HOEs 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. The light from a He-Ne laser (λ=633nm) was expanded by a spatial filter and collimated by a lens. The collimated beam was then partially transmitted by a glass coated silver halide emulsion layer. The light beam illuminating the surface of silver halide emulsion served as reference wave for recording the HOE. The transmitted beam through the silver halide emulsion layer illuminated the object, a flat diffusely reflecting plate. The light scattered by the object illuminated the silver halide layer from the rear side serving as an object wave. These two beams interfered at the recording plane to produce a reflection hologram.

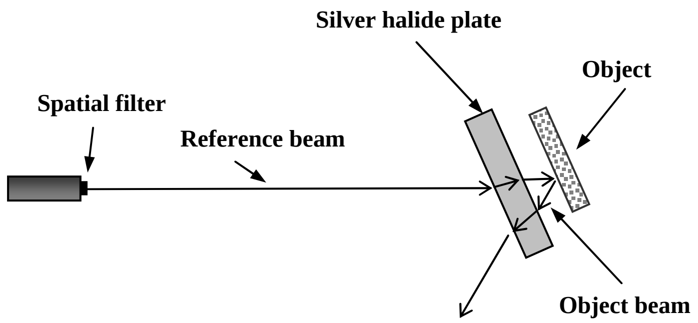


Fig. 1. Recording of the reflection hologram using the Denisyuk method.

3.2. Experimental set-ups

The two schemes of the ESPI systems using holographic optical elements are presented in Figures 2 and 3. Out of plane rotation of the HOE offers the possibility for fine adjustment of the reference beam intensity. Rotation of the partially reflective plate in Fig. 2 allows one to illuminate the object along its normal to ensure purely out-of-plane sensitivity of the system.

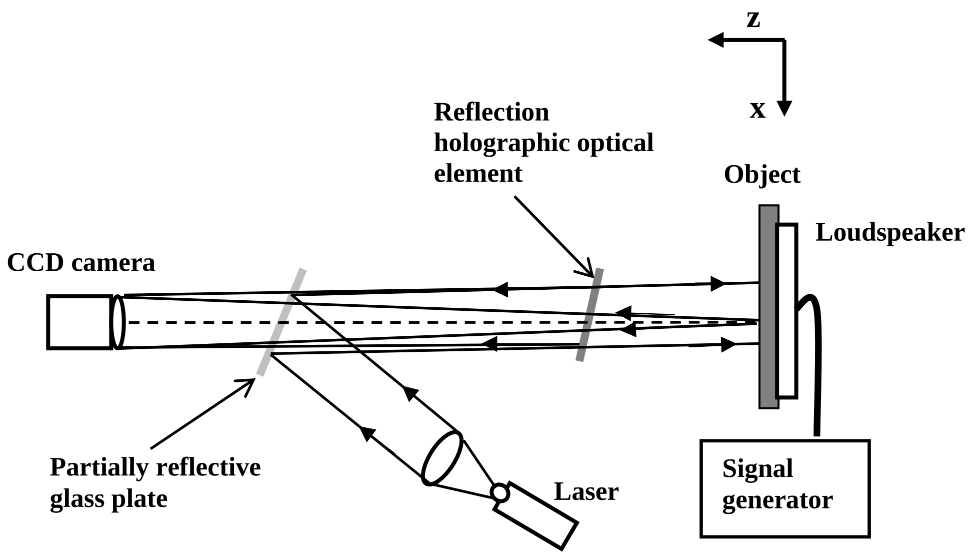


Fig.2. ESPI system with a holographic optical element and a partially reflective glass plate[6]

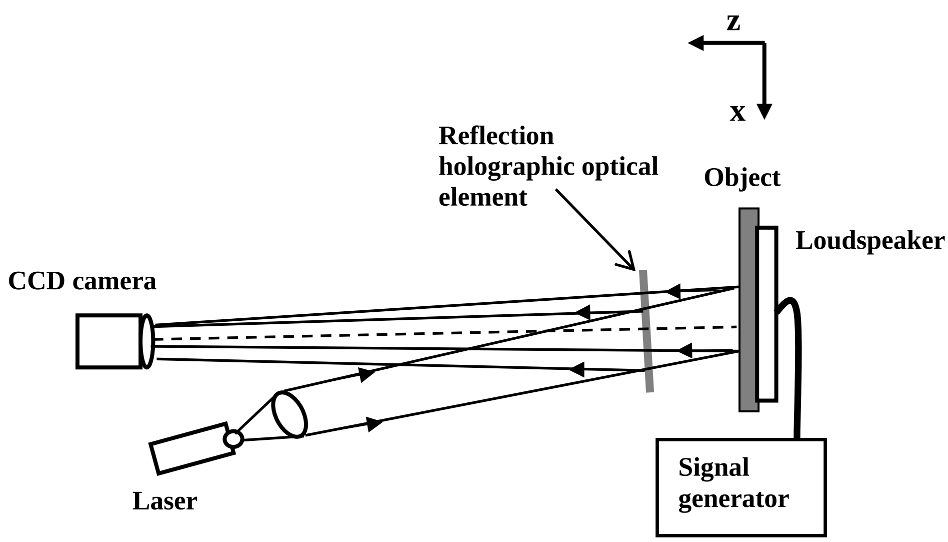
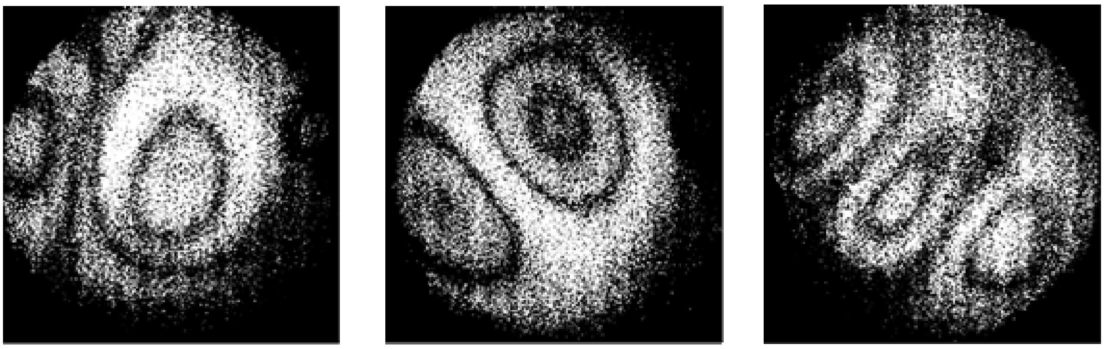


Fig.3. ESPI system with a holographic optical element only[7]

4. RESULTS AND DISCUSSION

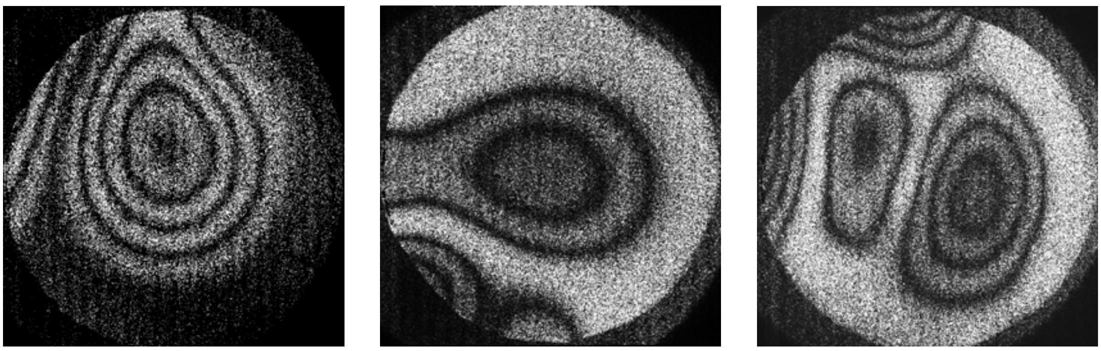
The two HOE-based ESPI systems were used in studying the vibration modes of an edge clamped aluminium diaphragm (40 mm diameter, 0.5 mm thick). The diaphragm was excited at different frequencies in the range from 2400 Hz to 7600 Hz by a loudspeaker placed behind it. The loudspeaker was driven by a sinusoidal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

Good quality speckle interferograms corresponding to various vibrational modes were recorded (Figs. 4, 5). Comparison of the shapes of the same vibration modes recorded with the two ESPI systems shows slight differences, especially for the modes recorded at 3200 Hz and 4100 Hz. This is due to the fact that the ESPI system with one HOE only (Fig. 5) is not completely insensitive to in-plane movements. Table 1 presents the comparison results for some important parameters for the two HOE-based ESPI systems.



a) 2400 Hz **b) 3200 Hz** **c) 4100 Hz**

Fig.4. ESPI vibration modes of an aluminium diaphragm recorded with the ESPI system with HOE and partially reflective glass plate. The amplitude of the sinusoidal signal driving the loudspeaker is 1 V. The field of view is 40 mm x 40 mm.



a) 2400 Hz **b) 3200 Hz** **c) 4100 Hz**

Fig.5. ESPI vibration modes of an aluminium diaphragm recorded with the ESPI system with one HOE only. The amplitude of the sinusoidal signal driving the loudspeaker is 1 V. The field of view is 40 mm x 40 mm.

Table 1
Comparison of the two HOE-based ESPI systems

Parameter / ESPI system	Maximum field of view	No. of components	Cost
with a HOE and a partially reflective glass plate	60 mm x 60 mm	4	low
with one HOE only	60 mm x 60 mm	3	low

4. CONCLUSIONS:

Two optical set-ups for electronic speckle pattern interferometry (ESPI) using holographic optical elements are presented:

- ESPI with a HOE and a partially reflective glass plate
- ESPI with one HOE only

Both ESPI systems are simple and compact:

- the first ESPI (4 components) is sensitive only to out-of-plane displacement of the object;
- the second ESPI (3 components) is not completely insensitive to in-plane displacement but the illumination and observation directions can be made nearly collinear.

It is demonstrated that both HOE-based ESPI systems 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.

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REFERENCES

1. Butters J. N., Leendertz J. A., “Speckle pattern and holographic techniques in engineering metrology”, ***Optics and Laser Technology*** **3**, 26-30 (1971).
2. Jones R. C. and Wykes C., ***Holographic and Speckle Interferometry,*** Cambridge: Cambridge University Press (1989).
3. Davies J. C. and Buckberry C. H., “Television holography and its applications”in ***Optical Methods in Engineering Metrology***, Ed. D C Williams, London: Chapman and Hall. (1993).
4. O.J. Lokberg, “Recent developments in video speckle interterometry” in ***Speckle metrology***, Ed. R. S. Sirohi, New York: Marcel Dekker (1993).
5. Rastogi P. K., ***Digital speckle pattern interferometry and related techniques***, New York: Wiley (2001).
6. Mihaylova E. M., Bavigadda V., Jallapuram R., Toal V., “Whole field out-of-plane vibration analysis with a HOE-based ESPI system”, Eighth International Conference on Vibration Measurements by Laser Techniques: Advances and Applications, Ed. E. P. Tomasini, ***Proc. of SPIE*** **7098**, 70980M (2008).
7. Bavigadda V., Jallapuram R., Mihaylova E., Toal V., “Design and fabrication of holographic optical elements for applications in electronic speckle pattern interferometry and laser Doppler vibrometry”, Eighth International Conference on Vibration Measurements by Laser Techniques: Advances and Applications, edited by Enrico Primo Tomasini, Ed. E. P. Tomasini, ***Proc. of SPIE*** **7098**, 70980O (2008).