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AN IMPROVED SHEROGRAPHY TECHNIQUE FOR SPATIAL DIFFERENTIATION

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SYNOPSIS

In this work we describe a new device designed to obtain a high quality experimental measurement with shearography. With this setup the spatial differentiation, up to the third order of out-of-plane displacements can be directly obtained. A compact setup with a high resolution camera was developed to capture the spatial derivatives. The quantitative measurements are obtained from the phase maps computed with four images phase shift technique. Good quality measurements of the higher order spatial differentiation were obtained by optical and digital means without the need of advance post processing. The border problem is also discussed and the results up to the third order are compared with the analytical solution.

INTRODUCTION

The spatial differentiation of the displacements is essential for a full characterization of the mechanical behavior of the materials. On thin plate structures the spatial differentiation are directly related to internal stresses, according to the Kirchhoff theory (Timoshenko and Woinowsky-Krieger 1959). Another advantage of obtaining high order spatial differentiation is its higher sensitivity to the change of mechanical properties along the structure. The measurement of stiffness change is a common approach used in non-destructive inspection of damaged laminated composite materials (Cawley and Adams 1979; Wahyu Lestari 2005). The shearography technique measures directly the first derivative of surface displacements. However, being a speckle reference interferometer, shearography leads to noisy results. In the present work an effort was made to improve the quality of the experimental data in order to get a direct measurement of displacement derivatives which can be differentiated afterwards. The second derivative can be obtain directly by using auxiliary optics (Murukeshan, Seng et al. 1998), but the quality of the results are very poor compared to the shear maps. A different approach, based on numerical differentiation of noisy experimental data was presented (H.M.R. Lopes 2005). This technique shows good quality results in derivatives up to the third order. Nevertheless during the calculation some important signal components were eliminated in the filtering process, which have a smooth effect on derivatives. Two alternative approaches are presented in this work. Both based on the information obtained from high quality shearography measurements. The first method is described as an optical approach. Several shear maps are acquired with different well known shear amplitudes. According to the derivative order they are linearly combined by digital processing. The second approach is called digital method and only one shear map is required. In this case, the derivatives are obtained by linear combination of digitally shifting shear maps.

DEVELOPMENT OF SHEAROGRAPHY PROTOTYPE

Shearography is a holographic interferometry setup which allows the direct measurement of the displacements first derivative. The elimination of the reference beam simplifies the optical setup and the use of a common path interferometer reduces the coherence length needed for the laser illumination. This is a non-contact field technique that can be used to perform measurements with a high resolution, close to 10^{th} of a micrometer. In the present case, the shearography with temporal phase technique were used to assess the spatial derivative on the surface of diffuse objects. The setup developed was based on the Michelson interferometer and was initially build on the top of an optical bench. A solid state LASER, Verdi from COHERENT, with a wavelength $\lambda = 532 \text{ nm}$, was used as light source. A schematic presentation of the setup is shown in figure 1.

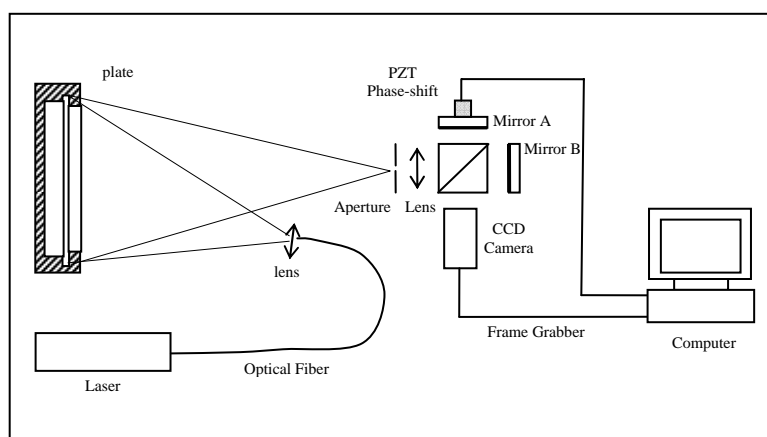


Figure 1- Schematic presentation of the experimental setup.

The apparatus was adjusted for optimizing the contrast of the recorded fringe patterns. From the elements position a model was built in the SolidWorks[®]. The optical alignment, positions and characteristics of each component were considered during the developing of the setup. A compact and robust solution was achieved by mounting the interferometer in a single aluminum block. The precision of optical alignment combined with high quality optical components, typically $\lambda/10$, assured a good optical performance. A JAI CV-M2 camera with 1200x1600 pixels and 10 bits resolution was used to capture fringe patterns. The shear amplitude was controlled by tilting the mirror B and the phase maps were computed from four recordings obtained with different positions of the mirror A, as can be seen in figure 1. The mirror displacement was produced in a controlled way by the span of a piezoelectric (PZT), derived by a signal generator National Instruments[®] PCI-6722 board. The high stiffness and small dimensions of the prototype assure the stability of the components and even allows measurements in industrial environments; the prototype is depicted in figure 2.

EXPERIMENTAL SET-UP

The out-of-plane rotation field was measured on a steel thin plate with 202 mm x 152 mm surface. The plate was clamped along all edges and a uniform pressure of 180N/m^2 was applied from the back, see figure 1. The shear prototype and the LASER were used to record the out-of plane spatial derivative for different shear values. The four images phase-shifting technique was applied to extract the phase distribution from the recordings. The shear was previously adjusted by imaging a metric scale placed closed to the surface and controlled by

two micrometric screws. Due to the high resolution demands of this technique, the measurements were performed on the top of an optical bench to assure the isolation from external perturbations.

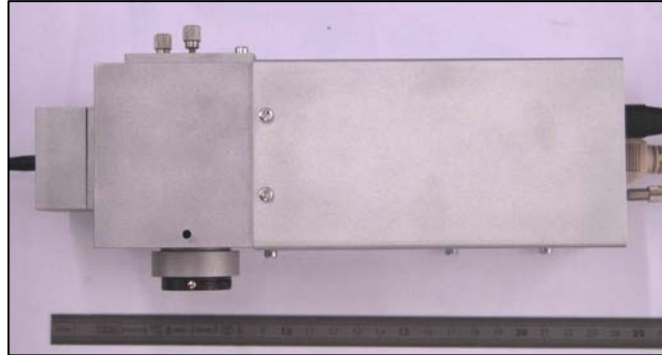


Figure 2- Shear measurement prototype.

RESULTS

The phase map of each measurement was extract from the two sets of four intensity recordings obtained before and after the uniform pressure being applied. To compute the phase o each pixel corresponding to one object state the four intensity recording were processed with the following equation;

$$\phi = \tan^{-1} \left[\frac{I_4 - I_2}{I_1 - I_3} \right] \quad (1)$$

The phase map ϕ_{Amp} is retrieved by subtracting the reference phase ϕ_{ref} to the deformation phase ϕ_{def} , according to the equation;

$$\phi_{amp} = \begin{cases} \phi_{def} - \phi_{ref} + 2\pi \dots \text{if } \phi_{def} < \phi_{ref} \\ \phi_{def} - \phi_{ref} \dots \text{if } \phi_{def} > \phi_{ref} \end{cases} \quad (2)$$

As it can be seen in figure 4 the spatial derivative phase map was obtained from 10 mm and 20mm horizontal shear values. As result of the shear the border effect was increased and phase maps become smoother.

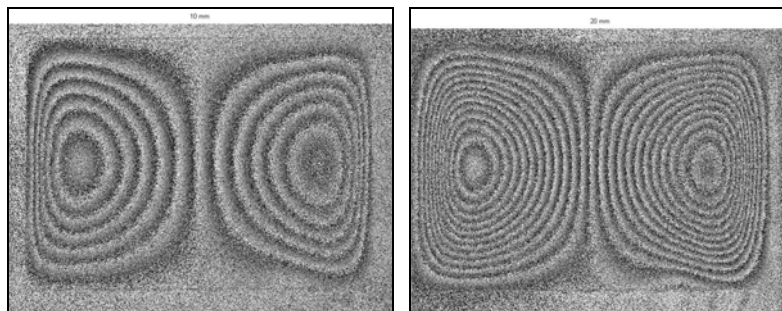


Figure 4 - Phase map with horizontal shear 10 mm (left) 20 mm (right).

The rotation field can be build up from the phase map spatial derivative by using the phase filters and unwrapping techniques. On the case of shearography measurement the rotation map was obtained from the following equation;

$$\frac{\partial w}{\partial i} = \frac{\phi_{unw}}{\mu} \frac{\lambda}{2} \dots i = x, y \quad (3)$$

where the λ is the wave length, ϕ_{unw} is the unwrapped phase map and μ the shear distance.

The high order spatial derivatives obtained by optical approach were based on linear combination of several rotations maps obtained with well known shear distances. The recording of four rotation maps was necessary to obtain the third order spatial derivative of the displacements. In the figure 5 are depicted the four rotation maps recorded in each plate direction.

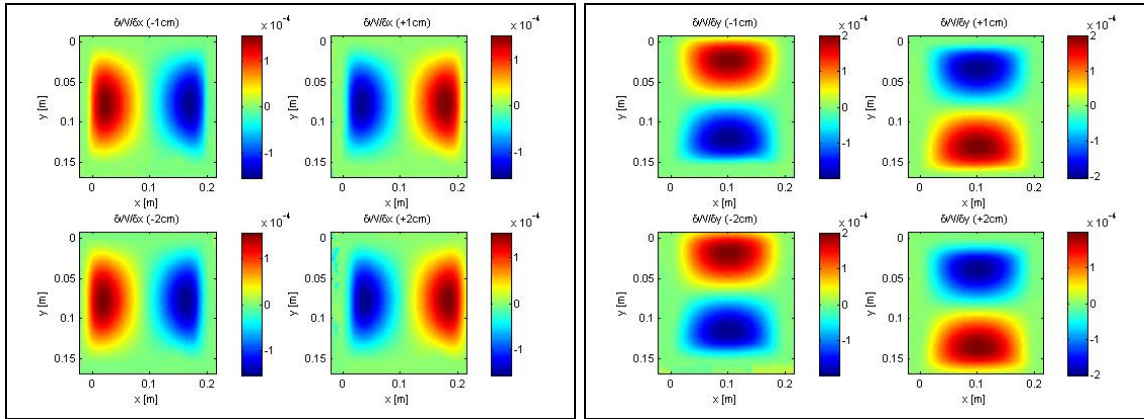


Figure 5- Rotation maps for horizontal and vertical directions.

The curvature of the plate was calculated by subtracting two rotations maps with different shear distances. Consequently, the third order derivative was obtained by combining the two computed curvatures, the maps for both, horizontal and vertical, third order derivative are depicted in figure 6.

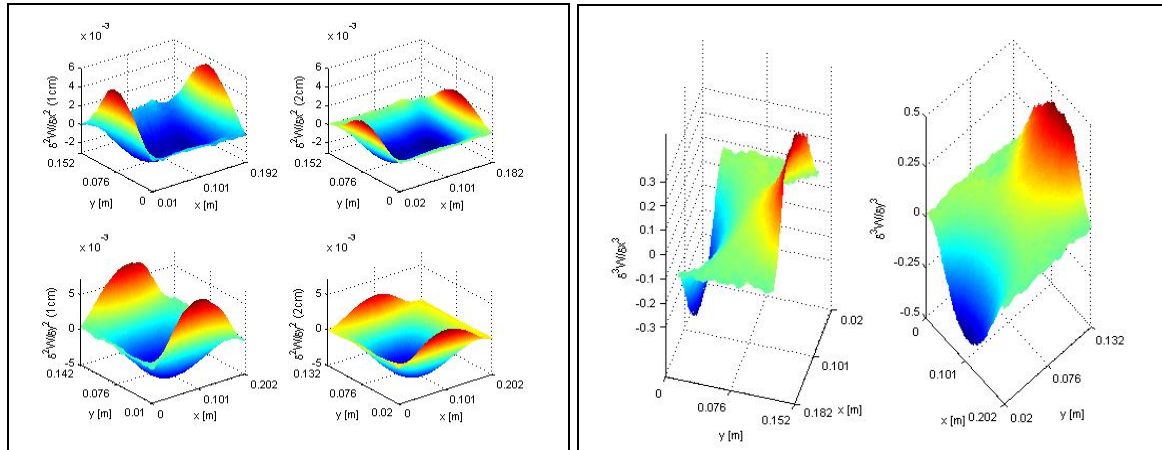


Figure 6- The curvatures and third spatial derivative maps obtained by optical approach.

As result of the border effect the curvature and the third spatial order maps are only valid within the shear distance from the border. That explains the amplitude differences between the curvatures in the regions close to the boundaries.

The digital approach was based on the recording of a single rotation map and then the spatial derivatives by subtracting the digital shifted rotation map. In the figure 7 is depicted the third order spatial derivative profile along the horizontal mid plane with different shears. As expected, the shear increase produce a smoother profile but also enlarges the border effect.

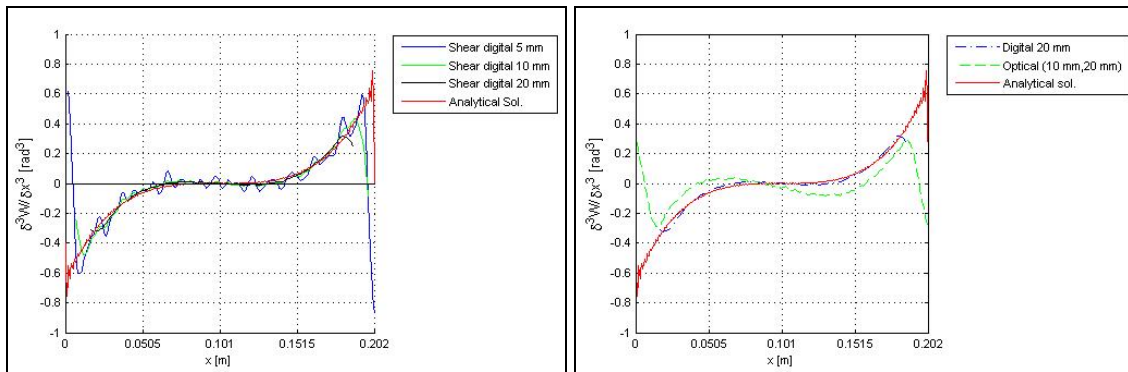


Figure 7- Third order spatial derivative profile by digital approach and obtained with the proposed technique. Both results are compared with the analytical solution.

The computed results with the proposed techniques are compared with the analytical solution for the third order spatial derivative, figure 8. As shown, the digital leads to better result by using 20 mm shear, while 10 mm and 20 mm shear is used in the optical technique.

CONCLUSIONS

In this paper two different techniques measurement of displacement spatial derivatives up to the third order were presented. This was possible due to the good quality of the fringe patterns recorded with the designed shear device. The proposed procedure is straightforward and no advanced post processing is needed. The border affected resulting from shearography technique increases with the shear distance. However, the results obtained by the two techniques are very close to the analytical prediction. The digital approach produces better results than the optical one. This may be explained by error accumulation due to the combination of different rotation maps.

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REFERENCES

- Cawley, P. and R. D. Adams (1979). "The Location of Defects in Structures From Measurements of Natural Frequencies." *Strain Analysis* **14**(2): 49-57.
- H.M.R. Lopes, R. M. G., M.A. Vaz (2005). "An Improved Mixed Numerical-Experimental Method for Stress Field Calculation." submitted to *Optics & Laser Technology*.
- Murukeshan, V. M., O. L. Seng, et al. (1998). "Polarization phase shifting shearography for optical metrological applications." *Optics and Laser Technology* **30**(8): 527-531.
- Timoshenko, S. and S. Woinowsky-Krieger (1959). *Theory of plates and shells*. New York,, McGraw-Hill.
- Wahyu Lestari, P. Q. (2005). "Damage detection of fiber-reinforced polymer honeycomb sandwich beams." *Composite Structures* **67**: 365–373.