A Hybrid Technique for Damage Detection on Laminated Plates

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ABSTRACT: This work presents an experimental/numerical technique for delamination damage detection on thin laminated composite plates. The delamination is identified using a technique based on the curvature differences of the plate modes shapes measured before and after impact damage. The natural frequencies are extracted from Frequency Response Functions. A double pulse TV holography is used for no-contact and accurate measurement of the amplitude mode shapes. The curvature is obtained by applying an improved differentiation/smoothing technique to the experimental data. Finally, the curvatures of each mode are subtracted and the damage is located.

1. INTRODUCTION

Nowadays, composite materials have a widely use in structural construction owing to is strength/weight ratio. The low impact energy absorption capabilities of these materials lead in the last years to the developing of new non-destructive inspection techniques. The delamination damage is the most common non-visible defect that appears on the laminated panels, and can highly affect its mechanical strength. In this work an alternative non-destructive technique for damage detection on polymeric matrix composite materials is presented. The methodology is based on curvature differences computed from the measured mode shapes in the sound and damage plate. The Abdo and Hori [1], numerical simulations showed that the identification of structural damage by mode shapes can be more easily accomplished by the rotation differences. Also, the numerical simulation made on an isotropic beam proves that the sensitivity to damage detection grows with the spatial differentiation order of the displacements. The rotation field could mislead to the identification of small defects on polymeric matrix plate, when noisy experimental data is used. In these cases, a higher sensitivity parameter like the curvature or strain energy could be used for damage identification [2, 3]. On the other hand, the mode shapes curvature involves the computation of second spatial differentiation of displacement fields which amplifies the noise. A new algorithm, based on a differentiation/smoothing technique was used to overcome this problem [4, 5].

2. EXPERIMENTAL SETUP

A carbon fiber thin laminated plate with $[0/90/+45/-45/0/90]_s$ was tested in this work. The natural frequencies and correspondent mode shapes of the plate were measured in a free-free condition. The plate was suspended with very flexible rubber bands. A dynamic analyser Oros 35 with an impact hammer PCB model 084A17 and a Polytec Vibrometer model OFV3001 were used for non-contact measurement of the plate Frequency Response Functions (FRFs). From the measured FRFs the first 14 natural frequencies were identified in the frequency band between 0Hz and 1kHz. The modes shapes were characterized using a double pulse TV holography with the plate acoustically excited by a loudspeaker. The experimental setup is shown in Fig. 1. In this setup, a LUMONICS Ruby LASER is used to generate pairs of pulses with a time separation ranging from 1μs to 800μs. The double pulse holograms were recorded by a CCD camera and the relative positions of the plate vibration are captured [6]. The measurement is synchronized by the excitation signal and the trigger level adjusted for the maximum gradient of the plate displacement. This technique allows a non-contact with a high sensitive and high resolution measurement of the mode shapes. The intensity of the acoustic excitation was adjusted according to the resolution of this technique. The effect of any rigid body movement of the plate is minimized due to the short elapse time between recordings.

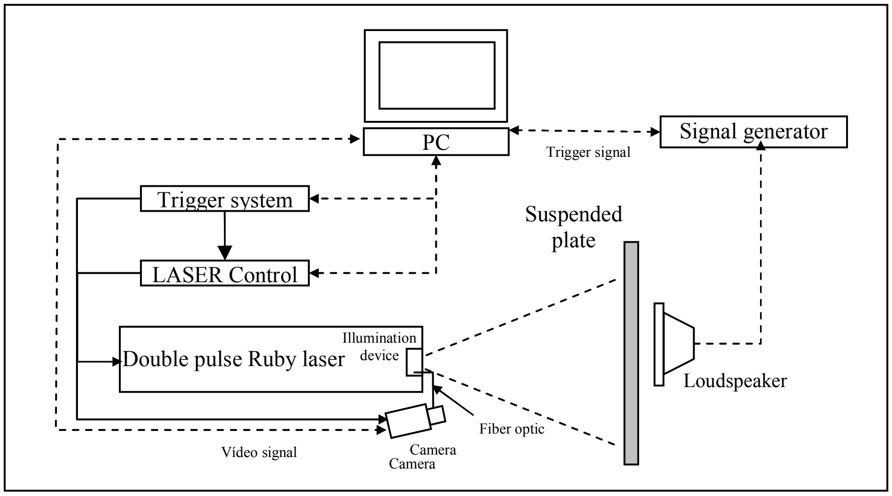

Figure 1- Schematic presentation of the experimental set-up.

To obtain the plate mode shapes the phase distribution of each interferogram has to be computed. In the present setup the phase map of each recording is obtained by demodulation of a spatial carrier introduced into the primary fringes. The procedure is performed using fast Fourier transform and by identifying the wave number frequency of the spatial carrier, as can be seen in Fig. 2. These noisy phase maps are post-processed using dedicated image processing techniques for accessing the continues mode shape displacements [7-13]. In Fig. 2 summarizes the procedure used in the calculation of amplitude mode shapes from the recorded holograms.

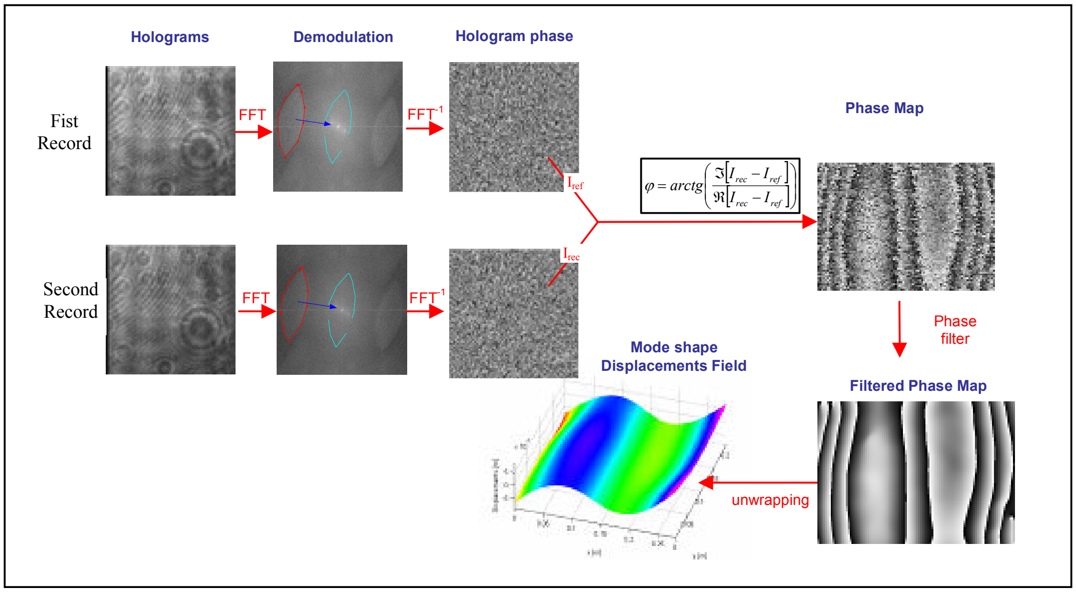

Figure 2- Post-processing procedure for accessing to the mode shape displacements field.

The phase filter techniques used allowed the increase of the measurement accuracy by reducing the noise and eliminating phase discrepancies. An effective technique was used to obtain nearly free noise phase. A simple unwrapping technique was applied to the filter phase maps and the mode shapes were obtained almost without errors. A general view of the set-up for FRFs and mode shape measurements are depicted on Fig. 3. The FRFs measurements with laser vibrometer were performed in the plate's corner to avoid nodal lines. For the mode shape measurements, the plate's surface was covered with a thin layer of white powder to obtain a uniform reflection of the LASER light, Fig. 4.

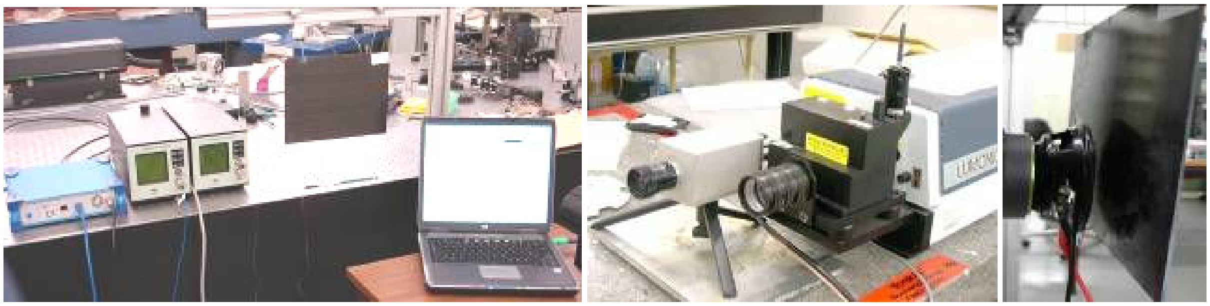

Figure 3 - General view of experimental set-up for FRFs, mode shapes measurement and acoustic excitation.

A small damage was introduced inside of the polymeric matrix by dropping a 9N sphere from 2,7 meters high into the plate surface. This way a 26 J impact was applied on the plate surface. The plate was clamped to a supporting structure on two opposite edges. Special care was taken during the impact test to avoid the impact rebounds. After the impact no visible damage could be observed on the plate surface, Fig 4, only a small indention reveals the impact point.

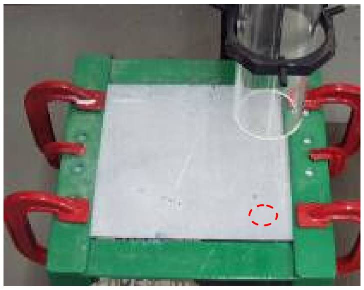

Figure 4- Impact test set-up.

The plate natural frequencies and mode shapes were again measured by following the procedure described above. Non-contact measurements permit the reproduction of the same initial conditions, which makes the comparison between the two situations more accurate. The mode shape curvature is obtained by the second order spatial differentiation of each mode displacement field. The numerical procedure is accomplished by combining filtering and differentiation techniques, and is performed according the following diagram:

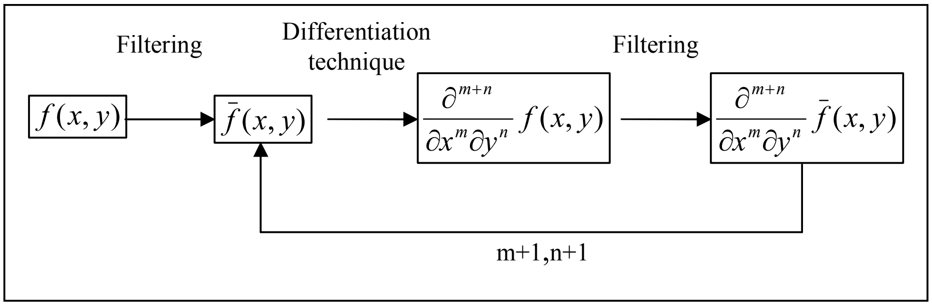

Figure 5 - Schematic diagram for numerical differentiation.

3. RESULTS

The Fig. 6 shows the two FRFs measured for undamaged and damaged plate. As can be seen in the graphic presentation, the natural frequencies of damaged situation are a bit smaller than the undamaged ones. These differences are more clear in the higher frequencies, and suggests the decreased of plate stiffness is due to inside delaminations.

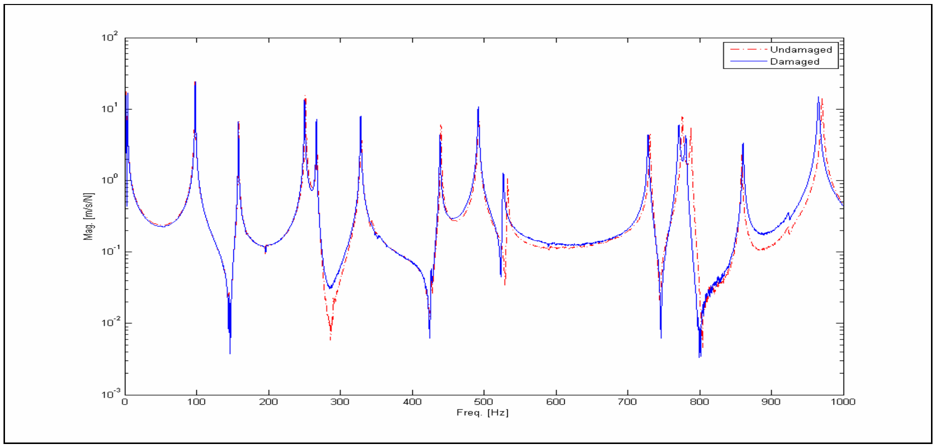

Figure 6- The Frequency Response Functions of the undamaged and damage plate.

The difference on the natural frequency is explained by the mode shape strain energy reduction and reflects on the mode shape amplitude deviation. The mode shape differences can be evaluated by computing the normalized amplitude between the two measurements. The highest deviation was obtained for the sixth mode shape, although the shape differences between modes are minimal, as can be seen in the Fig. 7.

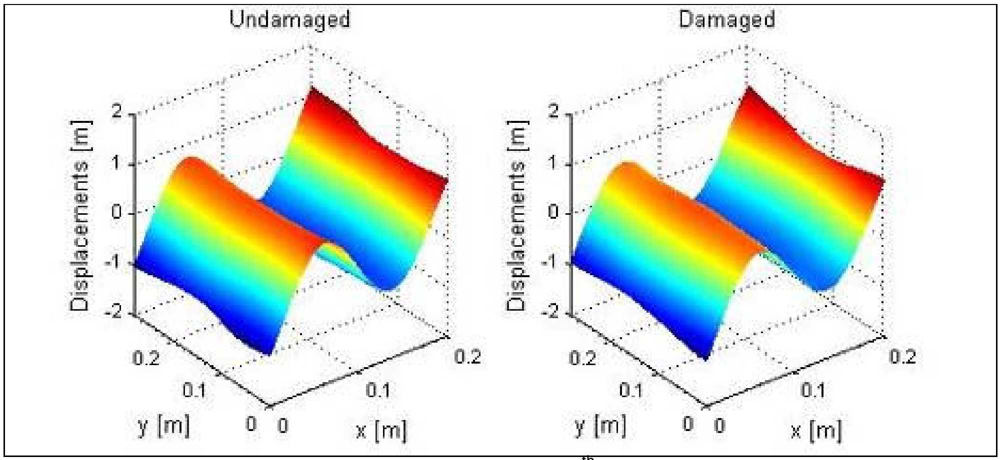

Figure 7 - The undamaged and damage 6th mode shape amplitude.

The curvature of the mode shape was numerically obtained by using the differentiation procedure of the Fig 5. From the curvatures differences one can identify the location of the damage generated on the plate. The Fig. 8 presents the modulus of curvature xy differences for 6th mode shape. The delamination location can be clearly identified in this map and is coincident with impact location.

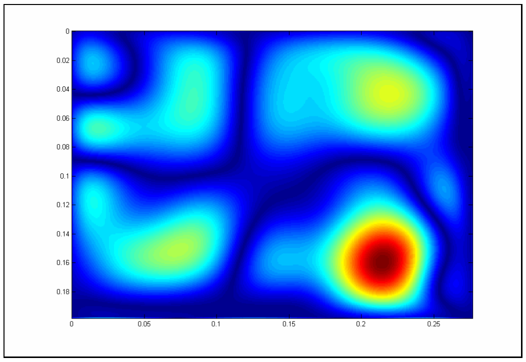

Figure 8- Damage identification (on the bottom right side).

4. CONCLUSIONS

Based on the hybrid technique presented was possible to identify internal damage on a laminated composite plate. The results obtained for the other modes aren't so conclusive. The fact of working with a small damage and using noisy measurements can lead to unexpected results. Best results could be achieved by measuring the rotation field with TV Shearography, this way a spatial differentiation is avoided in the curvature calculation.

5. REFERENCES

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