CONTACT-LESS FULL-FIELD OPTICAL MEASUREMENT METHOD TO ANALYZE VIBRATIONS OF STRUCTURES

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ABSTRACT

Structural vibrations can be measured with optical digital holography. Such a method provides measurements with a very high spatial resolution and is a contactless technique. This method is based on the interference between a reference laser beam and the field diffracted by the studied object. Using a high speed camera, it can also be implemented in the time domain to investigate non-stationary problems. Recent investigation shows the high-speed digital holography is comparable with classical laser vibrometry.

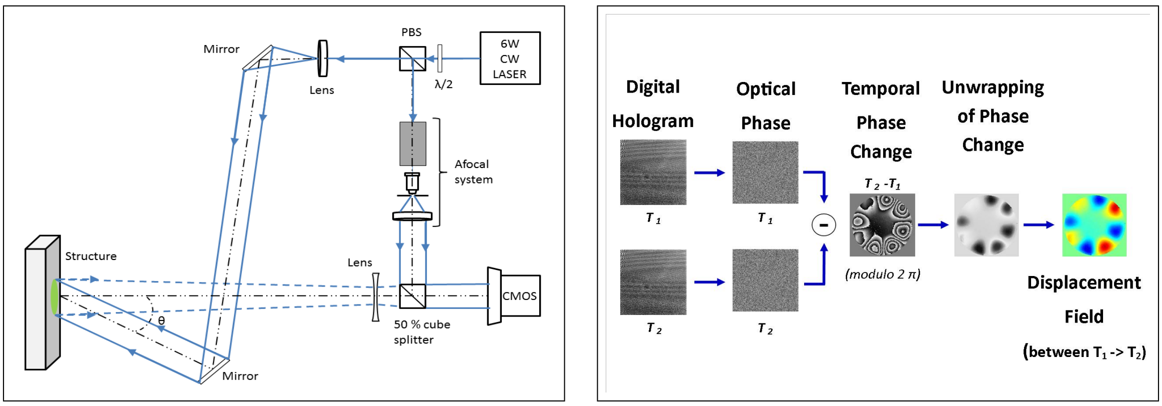
Acoustic Black Hole (ABH) effect is a innovative method to reduce the structural vibration. The vibratory field inside an ABH is characterized by a strong variation of the wavelength with space and an increase of the amplitude of the vibratory field at the extremity. In this paper, we present an experimental investigation of the vibratory field inside an Acoustic Black Hole on a beam.

1 INTRODUCTION

In the domains of acoustics, vibro-acoustics, vibrations of structures or flow-induced vibrations, both accelerometer and laser-vibrometry are the most favorite instruments for dynamic measurements. Accelerometer is robust and cheap but is a pointwise only a punctual sensor and is intrusive. Laser-vibrometry uses a laser beam to probe a dynamic object provides non-contact, high accuracy and high temporal resolution measurements. In order to get full-field data, a laser-scanning mechanism is required. This operation needs long time and the dynamic specimen under interest must be quite stationary (i.e. highly controlled excitation). Full-field evaluation can be obtained with holographic and speckle interferometry [1]. Vibration analysis with optical holographic interferometry began with the works of Powell and Stetson [2] who first established the principle of time-averaging. However, the stationary regime is a particular case for investigating the structure vibration behavior, and the characterization of structures under operational or real functioning conditions requires analysis in the time domain. Then, providing a real-time follow-up of the vibration amplitude, whatever the excitation condition, is a challenge for full-field optical metrology [3]. As examples, problems that can not be addressed by a stationary approach are: vibrations of panels induced by hydro or aero-acoustic sources, structural vibrations induced by squeak and rattle noise. We would like to take the opportunity of the DYNCOMP'15 meeting to discuss about the vibration field measurement of a structure supplying an Acoustic Black Hole.

2 PRINCIPLE : FROM HOLOGRAMS TO DISPLACEMENT FIELD

Basically, digital holography consists in recording an interference pattern using a sensor arranged as a matrix of pixels. In the set-up (Fig.1.a), the structure under interest is illuminated by a laser beam, which is then scattered by the object surface.



(a) (b)

Figure 1. (a) Optical set-up and (b) Illustration of digital hologram post-processing

A hologram H is a quadratic sum of the both reference wave and object wave, and is expressed as

$$H(x, y, t) = |R(x, y) + O(x, y, t)|^2, \tag{1}$$

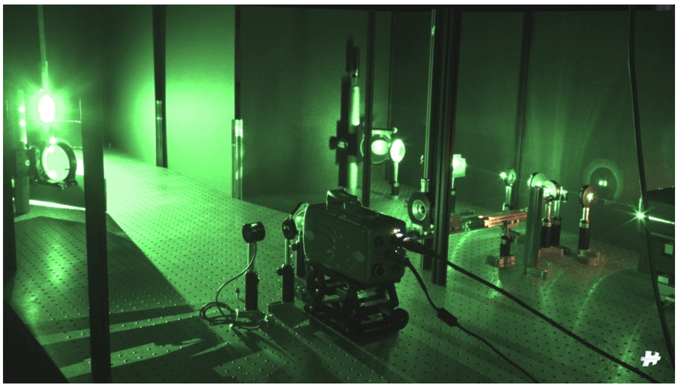
where $R(x, y)$ is defined as the reference plane wave. The object wave $O(x, y, t)$ is proportional to the object shape, and is described by

$$O(X, Y, t) = A_O \, exp(j(\varphi_o(X, Y, t) + \psi_o(X, Y)), \tag{2}$$

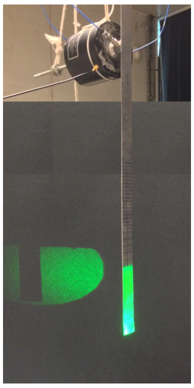
where A_O is the optical wave magnitude, $\psi_o(X,Y)$ is the optical surface phase and $\varphi_o(X,Y,t)$ represents the optical phase induced by the vibration field, in the object plane. The recorded hologram includes complex information related to the amplitude and phase. The phase is proportional to the optical path i.e. the distance between the object and the sensor. With two successive phase maps (Fig.1.b), a phase difference can be calculated. This phase is calculated through an inverse tangent function and is then obtained modulo 2 π. It exhibits 'numerical fringes' that can be interpreted as contour lines of the vibration. These numerical fringes need to be unwrapped to obtain a continuous phase map being directly proportional to the displacement field.

3 ACOUSTIC BLACK HOLE EFFECT MEASUREMENT

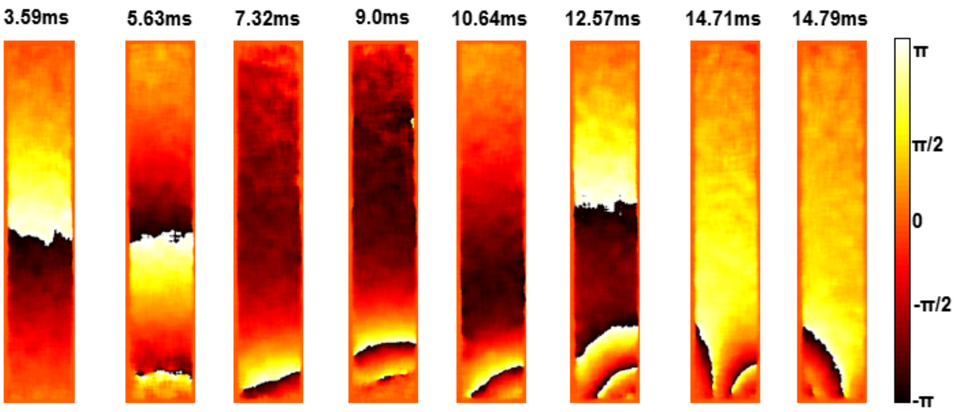
The Acoustic Black Hole effect is a innovative method to reduce the structural vibration. The ABH effect takes advantage of flexural waves properties in plates of variable thickness : Mironov [4] shows that if the thickness of the plate decreases sufficiently smoothly to zero close to the edge, waves slow down and stop without being reflected. Different works [5] have shown the complex behavior of the ABH extremity. We propose to take the advantage of the optical method with contacless and full field measurement, to analyze these local complex vibratory field. The optical setup is presented in Fig.2.a. In this study, a beam supplied a ABH extremity is placed vertically and is suspended to a shaker (Fig.2.b), and is excited by a linear sweep-sine from 20Hz to 10kHz.



(a)



(b)



(c)

Figure 2: (a) Experimental set-up, (b) Picture of beam with ABH suspended to a shaker and (c) Displacement map vs time evolution, result obtained with 512 x 128 pixels, and a time delay between each map at 125 μs

The observation area is 10cm x 2cm, corresponding to the lower extremity of the beam. Fig.2.c shows the phase change (mod.2π) recorded at different instants of the sequence with high-speed digital holography. The incoming 1D wave front can clearly be seen on the first pictures. A wave conversion can then be observed since the field presents a 2D component. This wave conversion may be due either to non plane incidence on the edge or to slight imperfections at the ABH tip.

4 CONCLUSION

This paper present with few words the principle of this new metrological tools for vibration analysis. High-speed digital holography give the possibility to a synchronous recording, of spatial and temporal information of vibration field. This method allows to observe the complex vibratory field on the edge of the beam supplying an ABH.

5 ACKNOWLEDGMENT

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