Structural health monitoring of a smart composite structure with a Time-of-Flight method

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ABSTRACT

Smart composite structures with a fully distributed set of integrated piezoelectric transducers are used to demonstrate the feasibility of embedded Structural health monitoring (SHM). Indeed, the piezo ceramics elements have been directly integrated into the heart of the composite during the manufacturing process. Then, a Time-of-Flight method has been applied. This technique is based on the duration measurements of a wave propagation with a simple and low cost experimental setup. Integrated piezoelectric transducers are used for monitoring the behavior of the structure.
In this research, special plates (with a piezo ceramics disk on each corner), made of glass fibre composite, are manufactured. Different kinds of damages are simulated on these plates, including holes with different diameters. Then a Time-of-Flight method is used for the SHM of these plates. Finally, the preliminary test results obtained on one plate are compared and discussed.

Keywords: Composite structure, Smart material, Piezoelectric transducers Integration, Health monitoring, Time-of-Flight method, Lamb wave.

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1 INTRODUCTION

Structural health monitoring (SHM) is a technology which combines advanced sensor technologies with intelligent algorithms to interrogate the 'health' condition of structures in real time or whenever necessary. SHM has been defined in the literature as the "acquisition, validation and analysis of technical data to facilitate life-cycle management decisions" [1]. The potential benefits of SHM technology include improvement of reliability and safety, enhancement of performance and operation, and reduction of lifecycle cost.

Several techniques have been investigated for detecting damage in composite materials. However, Lamb wave based methods have recently re-emerged as a reliable way to detect and potentially locate damages [2-5]. These techniques have been implemented in several ways in the literature, including the use of separate actuators and sensors to monitor transmitted waves and/or reflected waves, and multipurpose patches which both actuate and sense. Each of these techniques offer their own advantages and drawbacks in detecting certain types of damage with various levels of complexity.

This paper is focused on the structural health monitoring (SHM) of plates made of a glass fibre composite, by using a Time-of-Flight method. As lamb wave techniques provide more information about damage presence and severity than other tested methods (for instance, frequency response techniques), and provide the possibility of determining damage location due to their local response nature, this technique is selected. The paper is organized as follow. Section 2 shows the experimental setup and the experiment procedure. In Section 3, the results as well as the comparison of these results are presented and discussed. Then the concluding remarks are given.

2 EXPERIMENTAL PROCEDURE

The idea is to manufacture test plates, then simulate different damages on this plate and interrogate the 'health' condition of the structure with a Time-of-Flight method. When the signal travels from the piezo-ceramics actuator through the region where there is a change in material properties. Consequently, some changes are observed in the response signals from the piezo-ceramics sensor.

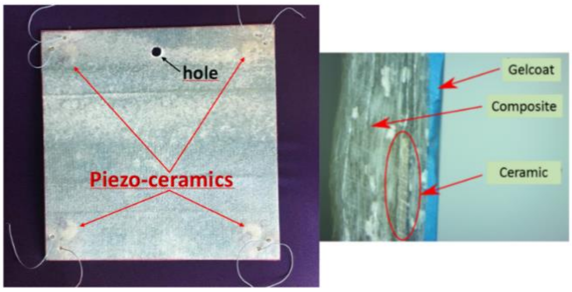

Figure 1. Samples to be tested - the Poisson's plates

The plates are instrumented with four piezo-ceramics, which are positioned at each corner of the plates, as shown in Figure 1. The characteristics of these transducers are given in [6]. The plates tested are 298 mm side and 2 mm thick with a gelcoat of 0.2 mm. The plates are manufactured in the Belfort-Montbéliard University of Technology (UTBM), France. These are laminated composites, composed of 6 layers of glass fibres and a polyester resin matrix. The technique of infusion is used as manufacturing method. The fibre volume ratio is about 35 to 40%. At the end, one layer of gelcoat is present on the top surface of the plates. The piezoelectric elements are placed between the first and the second layer. The layer of gelcoat is set as the reference for numbering of the layers. Then, to simulate strong and calibrated damages, holes with different diameters are drilled in the plates as shows in Figure 1. The main idea is to evaluate the potentiality of a ToF technique with a clear damage. The selected diameters are 4.5mm, 6mm, 8mm, 10mm, 12mm and 13mm, the holes were drilled in the same plate by increasing diameters and the measurement were done between two machinings.

The Time-of-Flight method exploits the ultrasonic wave propagation properties and, particularly, Lamb waves propagation properties [8]. Such waves have the particularity to spread over long distances in the composite [9]. To generate and capture the wave trains, the piezoelectric transducers integrated in the composite are used. The transducers have a resonant frequency for the radial mode measured in air around 100 kHz [6]. Once incorporated into the composite by backing effect, the central frequency of this radial mode decreases up to 64 kHz in the analysed plates. Then the frequency-thickness product (f.h) is around 0.15 MHz.mm. The phase velocity and the group velocity of the symmetric mode S_0 are then equivalent. So, it is possible to measure the S_0 group velocity and use the formulas of extraction of the materials parameters developed for the phase velocity [8].

After a set of optimisation tests, a short number of sinusoidal bursts (1 to 3 cycles) are chosen as the excitation signals. The experimental setup to generate and measure the wave trains is similar to the setup described in [7]. A function generator (Keithley, 3390) is used to generate excitation signals via a miniature power amplifier (PiezoDrive, PDM200B). The signals are then captured via a digital oscilloscope (Pico Technology, PS 4424).

3 RESULTS & DISCUSSION

For the experiments, the sinusoidal bursts signals travel through the structure between two piezo-ceramics actuator and sensor. A hole is drilled in the middle of this path (see Figure 1). The response signals obtained for the plate with different hole diameters are shown in Figure 2.

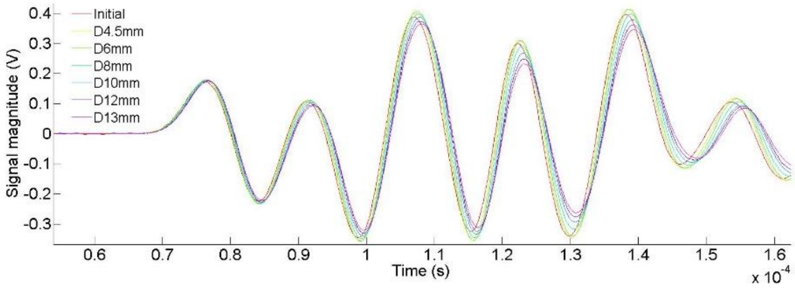

Figure 2. Response signals for the plate with a hole of different diameters

The time-of-flight from the actuator to the sensor has been recorded for each situation. At the same time, a Fast Fourier transform has been applied to deal with the data. The results are shown in Figure 3. To analyse the influence of the hole diameter on the FFT, we have selected an analysis frequency of 64 kHz, at which the FFT amplitude is maximum.

In Figure 3, the tendencies shown are quite clear for the Time-of-Flight vs hole diameter or the FFT amplitude at 64 kHz vs hole diameter. As it shows in the curve of FFT amplitude vs hole diameter, the vibration energy has a strong relationship with the damage index [10]. The bigger damage is, the weaker vibration energy will be, so the lower FFT amplitude will be.

These results give a quite good reference for the future investigations. Along this way, it is possible to use a Time-of-Flight method in Structural Health Monitoring.

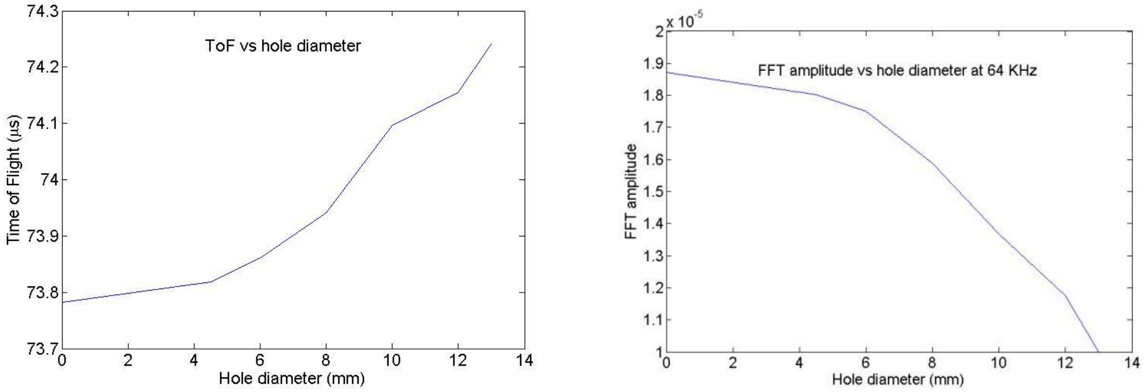

Figure 3. Tendency for different hole diameters

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