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ULTRASONIC GUIDED WAVES SENSITIVITY TO FLAWS NEAR PLATE EDGE

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Undele ghidate ultrasonore reprezintă o tehnică modernă de Control al Integrității Structurilor (SHM) pentru structuri uşoare precum cele utilizate în industria aeronautică. Undele ghidate se propagă în lungul plăcilor pe distanțe considerabile, fiind astfel capabile să indice prezența defectelor. O metodă de a genera unde Lamb este prin utilizarea de Compozite cu Micro-Fibre (MFC), un traductor inovativ care este elastic şi robust. Prezenta lucrare prezintă un model şi o simulare numerică ce contribuie la proiectarea optimală a unui experiment pentru detectarea defectelor şi o posibile implementări într-un sistem SHM îmbarcat cu aplicații aeronautice.

Ultrasonic guided waves represent a modern Structural Health Monitoring (SHM) technique used in light structures like those from the aeronautical industry. The guided waves propagate along plates for considerable distances, being thus capable to indicate the presence of flaws. One method to generate such Lamb waves is by using Micro Fiber Composites (MFC), which represent an innovative actuator, elastic and robust. This paper presents a numerical model and simulation results, which contribute to the optimum design of an experimental setup for flaw detection and possible implementation in an embarked SHM system with aeronautical applications.

Keywords: Structural Health Monitoring, Micro Fiber Composites

1. Introduction

The requirements for low weight and permanent Structural Health Monitoring (SHM) in modern structures having low safety margins, have recommended as a potential solution, the use of guided waves. Especially efficient for planar structures like wing plating of airplanes and space vehicles, but also for pressure vessels, the guided waves can propagate over relatively long distances and bring information about structural anomalies encountered in their path [1..4]. In counterpart, the interpretation of the signals from the discontinuities is considerably more difficult to interpret than the one from a classical pulse-echo method [5].

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The present paper is part of a wider research concerning monitoring and control of airborne structures. A plate, as a simplified model of a wing, is controlled by two Microfiber Composite actuators (MFC), reducing the wing forced vibration amplitude by following a certain control law. The SHM problem is intended to be solved for a reasonable defect size and frequency domain by using the same MFC actuators, as guided waves emitters and receivers. In the present work, a numerical simulation using the Finite Element Method (FEM) of the guided waves in a pristine plate and in a plate with a defect near the clamped edge provides information about the method possibilities and limitations.

2. Guided waves in plates

The guided waves in plates have been investigated theoretically [1..4] and using numerical methods. A new method has been developed using guided waves, which are specific waves propagating along the thin structure, for long distances. In the particular case of plates, these are called Lamb waves. They are influenced by the shape, size and position of a possible defect. The incident wave is reflected and possibly transmitted by the defect with amplitudes which depend on the defect characteristics. At some frequencies, the defect can be the source of other wave modes than the incident ones, identifying thus better the defect. The complexity of the problem is the reason for the numerous theoretical and experimental studies have been published in the last decades.

3. Differential equations of motion

A plate of constant thickness 2h=1.25mm is considered to have the material properties of aluminium: ρ=2700 kg/m^3, E=7 GPa, ν=0.33, representing the mass density, Young's modulus and Poisson ratio, respectively.

The Lamb waves correspond to stress free condition on the two surfaces of the plate. This condition, applied to the displacement field, leads to the so-called *dispersion equation* relating the wave numbers to the angular frequency [5, 6].

For any given frequency, there are minimum two waves which can propagate in a homogeneous plate, one with symmetric displacements distribution on the plate cross-section relative to the mean surface and another one with anti-symmetric displacements distribution (Fig.1).

The finite element method is used to solve the general differential equation of elasto-dynamics in two dimensions using the plane strain hypothesis:

$$\begin{aligned} \frac{\partial}{\partial x}\left(C_{11}\frac{\partial u}{\partial x}+C_{12}\frac{\partial v}{\partial y}\right)+\frac{\partial}{\partial y}\left(C_{66}\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)\right)&=\rho\frac{\partial^2 u}{\partial t^2} \\ \frac{\partial}{\partial x}\left(C_{66}\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)\right)+\frac{\partial}{\partial y}\left(C_{21}\frac{\partial u}{\partial x}+C_{22}\frac{\partial v}{\partial y}\right)&=\rho\frac{\partial^2 v}{\partial t^2} \end{aligned} \tag{1}$$

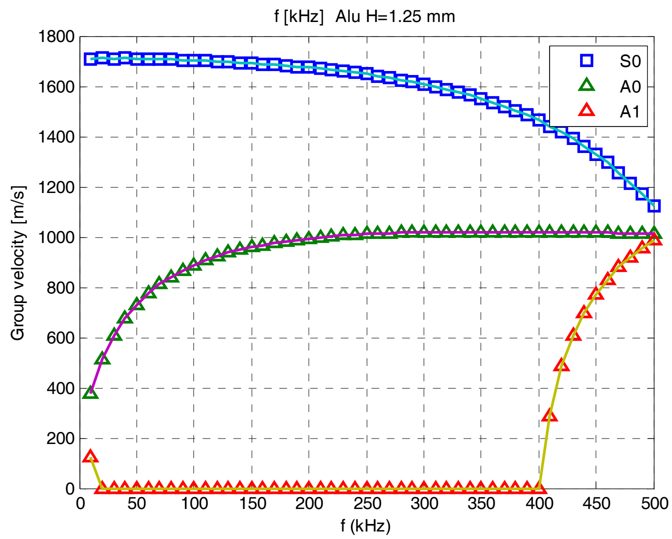


Fig. 1. Dispersion curves as group velocity vs. frequency for an aluminum plate

The elastic constants C_{11}, C_{12}, C_{22} and C_{66} are relating stress and strains according to the equation:

$$\begin{pmatrix}\sigma_{11}\\ \sigma_{22}\\ \sigma_{12}\end{pmatrix}=\begin{bmatrix}C_{11} & C_{12} & 0\\ & C_{22} & 0\\ Sym & & C_{66}\end{bmatrix}.\begin{pmatrix}\varepsilon_{1}\\ \varepsilon_{2}\\ \varepsilon_{6}\end{pmatrix} \quad (2)$$

4. Numerical simulation

The numerical simulation, carried out using the FEM method implemented in [7], provides the displacements, velocities, strains and stresses for the whole structure, as the waves propagate, with a time step of 1 μs, until t=150 μs. The boundary conditions correspond to a clamped plate along one edge and free on the others (Fig. 1). Three geometrical configurations have been tested: a pristine plate 400 mm in length and the same plate with a notch 0.25 mm and respectively 0.9mm deep and both having 0.1 mm opening. The notches are at 2.4 mm from the clamped edge, which corresponds to a small crack in the plate.

The MFC patch is 85 mm long and placed at 40 mm from the free edge. Submitted to a two cycles burst at 200 kHz central frequency, the MFC exerts linearly variable shear stresses along its length and Gauss modulated harmonic burst in time. The shear stresses are skew-symmetric about the center line of the MFC. This model corresponds with high accuracy to the epoxy mounted MFC on one experimental setup in the SIMOCA research grant.

The integration time corresponds to the fastest wave (S_0) propagation from the MFC towards the clamped edge and back, corresponding to typical fault detection in laboratory conditions.

The longitudinal displacements on the upper free surface of the plate are plotted as position-time diagram on Fig. 2.

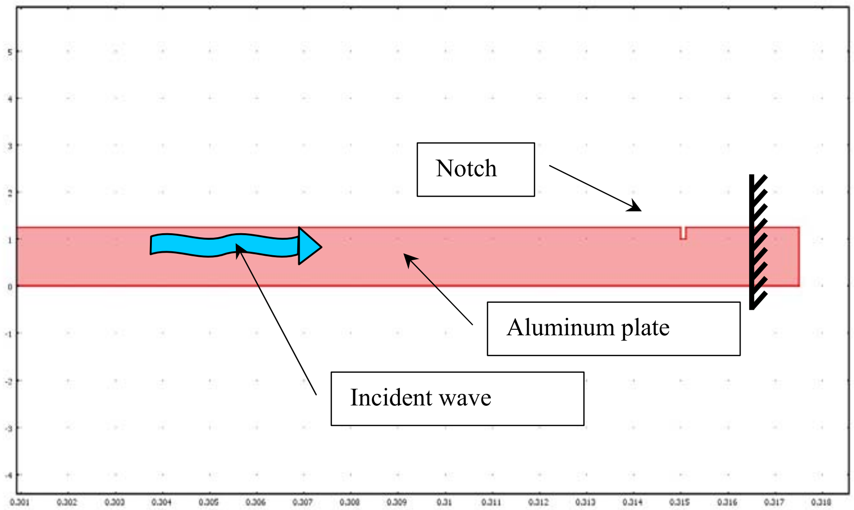


Fig. 1 Detail of the geometry with a notch near the clamped edge

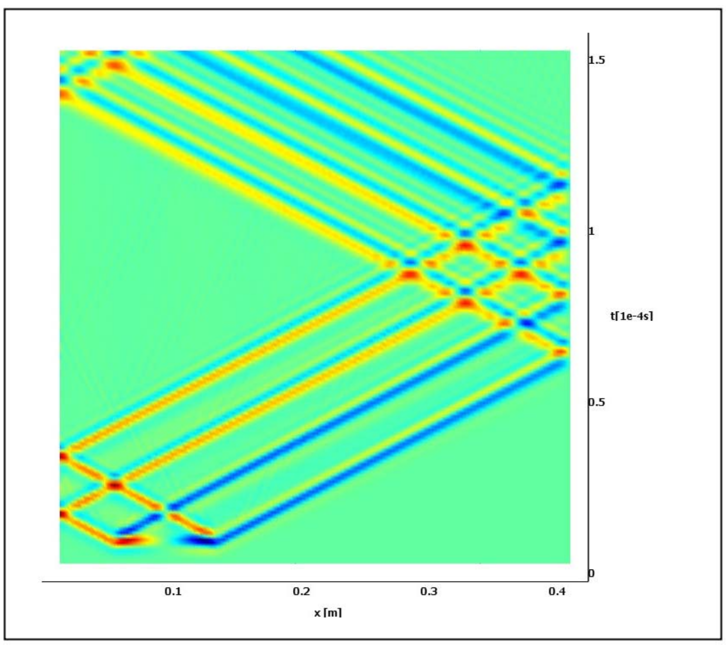
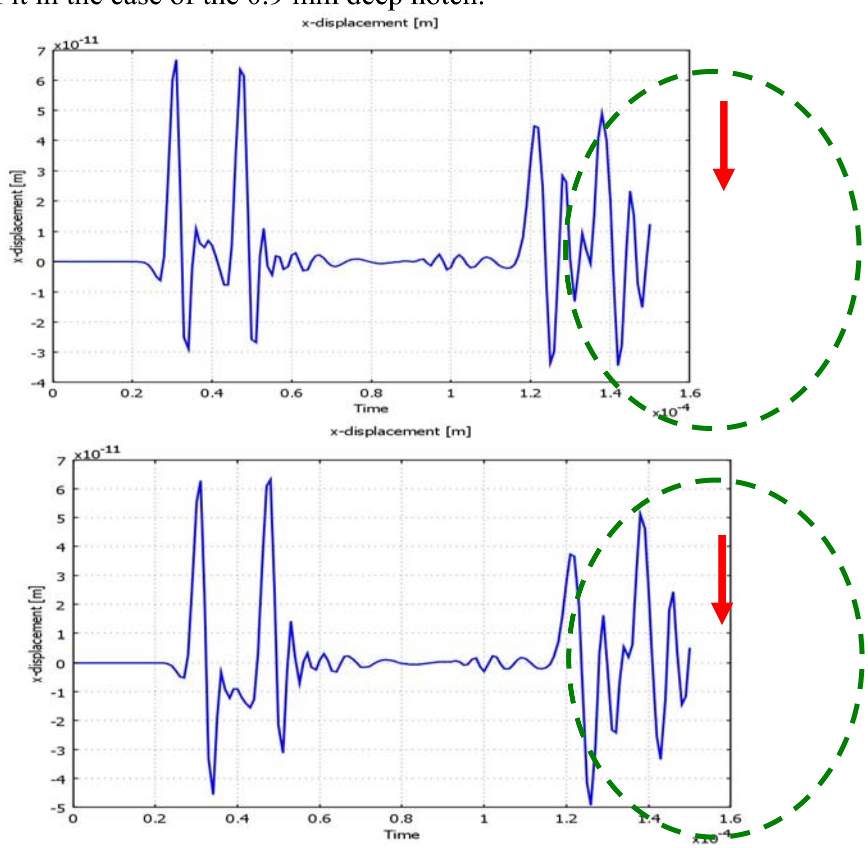


Fig. 2 Position-time diagram of the longitudinal displacements

The wave's propagation beginning is at the lower-left corner of the image. Four lines begin there. Both ends of the MFC are launching waves towards the clamped but also towards the free edge. The waves are reflected by the free edge and return towards the clamped edge. For this reason, the clamped edge is hit by four wave fronts.

If a notch is present, the reflected waves should carry information about its presence. In order to quantify this influence, the longitudinal displacements at the center of the MFC are shown on **Fig. 3**, for the pristine plate (up) and for the plate with a 0.25mm deep notch (middle) and 0.9mm deep notch (bottom). The reflected waves are encircled. The notches are much smaller than the wavelength (8.5mm for the S_0 wave and 3.5mm for the A_0 mode, both at 200 kHz) and, theoretically, the influence on the wave propagation should be negligible. However, the small resonant cavity formed between the notch and the clamped edge, produces a measurable effect. The second positive reflected peak (marked by a an arrow) diminishes from its value corresponding to the pristine plate, to 1/6 of it in the case of the 0.9 mm deep notch.



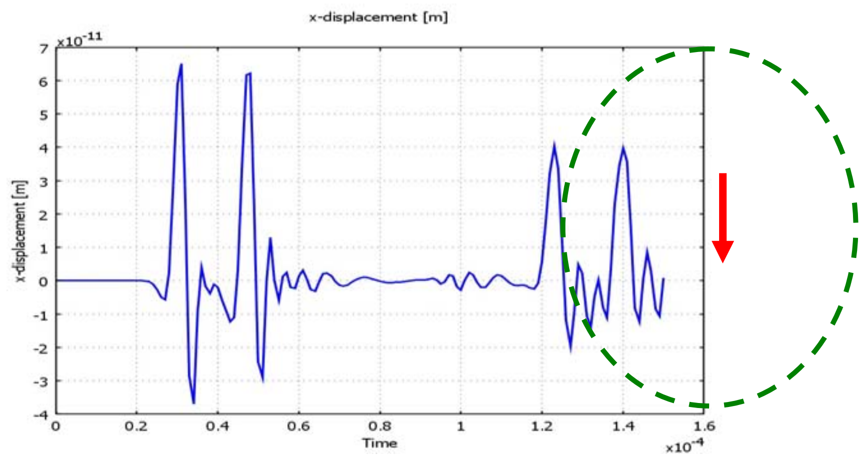


Fig. 3 Longitudinal displacement in the center of the MFC

6. Conclusions

The numerical simulation has proven that an unexpected parameter can be related to the depth of the notch, an encouraging step for the experimental phase.

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R E F E R E N C E S

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