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P047

MODELLING PROPAGATION OF LAMB WAVES IN CFRP PLATES FOR DAMAGE DETECTION

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1. Introduction

The scope of this paper is the presentation of application of modeling acoustic waves propagation in carbon fiber reinforced plastic elements for damage detection. This task is a part of the non-destructive testing methods which are very important in many industry branches. Many of construction elements are made of composite materials (e.g. plane's wings, components of cars coachwork). Due to importance of these elements they must be tested by means of NDT techniques during manufacturing and exploitation. The main reason to do that is to ensure the reliability of the whole constructions made of CFRP materials. One of the ways to detect flaws in laminate structure are techniques based on so called Lamb wave propagation. The mathematical background for this phenomenon was published by Horace Lamb in 1917 and since 1980s Lamb waves have been successfully used in SHM and NDT [1]. Theoretical models and experimental methods are still being developed mainly because of their advantages.

2. Mathematical formulation

The wave propagation in stress-free isotropic and anisotropic bulk media can be adequately described using theory based on linear stress-strain relationships: the stress equation of motion [2]: $\sigma_{ij,j} + \rho f_i = \rho \ddot{u}_i$. Hooke's law: $\sigma_{ij} = C_{ijkl}\varepsilon_{kl}$ and linear strain-displacement relationship: $\varepsilon_{ij} = \frac{1}{2}(u_{i,j} + u_{j,i})$ where σ is the Cauchy stress tensor, ε is the Cauchy strain tensor, ρ is the material density, $\mathbf{u}$ is the displacement, $\mathbf{f}$ is a vector of the external force, $\mathbf{C}$ is fourth-order stiffness tensor. Combining the above three equations one can obtain the system of differential equations of motion. This set of equations with associated boundary conditions can be solved analytically only for limited number of cases. One of the examples with existing analytical solution is the propagation of Lamb waves in thin isotropic plate (for example made of aluminum). In this case elastic oscillations are described by the Rayleigh-Lamb equations:

$$\frac{\tan(pd)}{\tan(qd)} = -\left[\frac{4k^2pq}{(k^2-q^2)^2}\right]^{\pm 1}$$

where: $p^2 = \frac{\omega^2}{c_L^2} - k^2$ and $q^2 = \frac{\omega^2}{c_T^2} - k^2$, k is wave number, ω is angular frequency, c_L is longitudinal phase velocity, c_T is shear phase velocity and d is half thickness of plate. In most cases the geometry, boundary conditions and potential defects complicate the situation and the only possible solution is to use a numerical model. A number of different numerical computational techniques have been developed and can be used for this type of analysis, for example finite difference method, finite element method, spectral element method, etc. In this work FEM is used because of its versatility and wide availability of both commercial and free software. The advantages of FEM include the ability to study Lamb wave propagation almost in any kind of the structure including geometry, inhomogeneities, defects, etc.

3. Results

The FEM model was first tested on thin isotropic plate. Obtained dispersion curves agree very well with analytical solution (Fig. 1). Next the method of determining elasticity constants was investigated to develop material properties by means of homogenization of representative volume element – RVE (Fig. 3). Based on obtained material properties a full-scale model for various scenarios was solved to find a potential defects in plates. It can be done for example by means of short time Fourier transform (Fig. 2) or wavelet transform. Finally the calculation for object with nontrivial geometry were performed to show that proposed method is robust and can be applied for real object made of CFRP materials (Fig. 4).

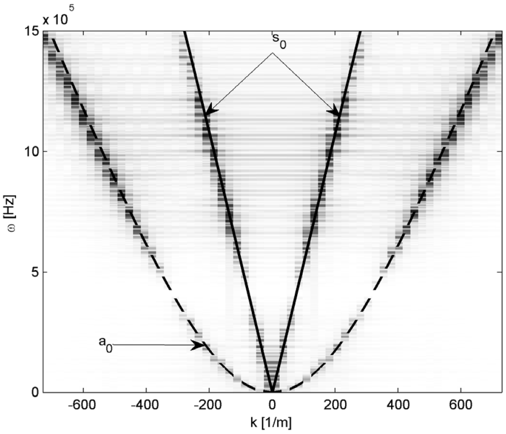

Fig. 1. Dispersion curves for isotropic plate.

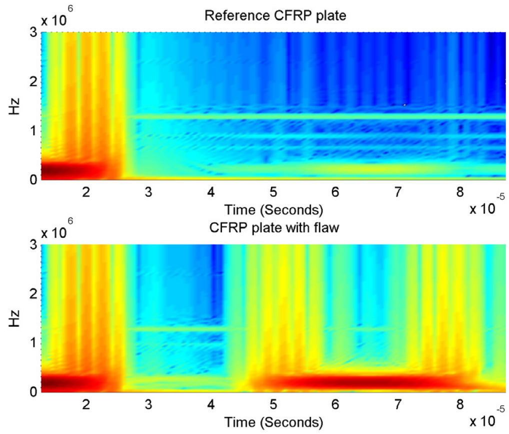

Fig. 2. Spectrograms of CFRP plates.

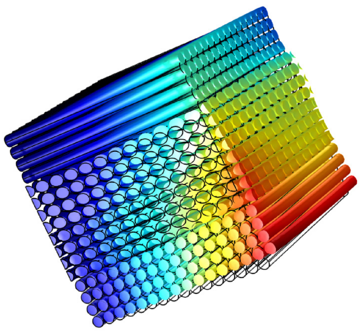

Fig. 3. Total displacement in RVE.

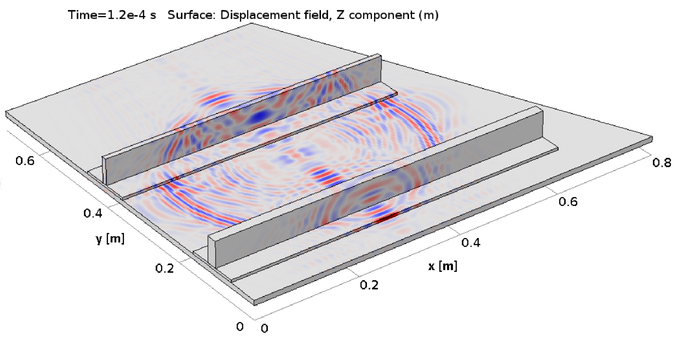

Fig. 4. Wave propagation in CFRP plate.

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References

1. Y. Lu, L. Ye, D. Wang, Z. Zhong and I. Herszberg (2009). *Damage detection in a large composite panel of five stiffeners using lamb wave signals*, Materials Forum, 33.
2. J.L. Rose (1999). *Ultrasonic Waves in Solid Media*, Cambridge University Press.