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LAMB WAVE DAMAGE DETECTION IN LAMINAR COMPOSITES

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The specific stiffness and strength of laminated composite structures have great advantages over metal structures. However, the sensitivity of composites to impact loads can initiate matrix cracks, which can eventually lead to delamination. Delamination is one of the most common types of defects in a laminated composite structure [1]. Deformations of this type can grow and affect the mechanical properties and structural integrity. These features lead to the need to detect delamination at the earliest stage. The propagation of Lamb waves in the region of a composite structure defect can create a local resonance, which is important for defect detection [2]. In particular, the diffraction of Lamb waves from a finite crack parallel to the surface has been well studied, where the effect of local resonance on wave scattering is recorded. The structure containing laminar composites can be optimized based on the engineering requirements for loading. A suitable load-bearing structure is created by using different ply orientations. However, the ply stacking sequence plays a determining role in the occurrence of delamination-type deformation [3]. Unidirectional ply stacking can cause delamination under load, but with a low probability. On the other hand, for cross-laminated laminates, there is a higher probability of developing an interlaminar crack at the boundary of two adjacent cross plies due to the development of interlaminar stress. Delamination may occur in different layers depending on the loading conditions. Localization of dynamic stress under impact loading may cause delamination in some other locations relative to where the impact load is applied. In the case of impact loading of a thick laminate, a matrix crack may appear on the upper surface and delamination may spread from top to bottom through the layers with increasing size. The characteristics of the Lamb wave packets can provide the necessary information for the flaw detection of laminated composites.

Delamination in a composite laminate divides the region into several waveguides according to the number of delaminations that may be present in the structure. Despite the relatively large number of studies on delamination detection using guided waves, the sensitivity of defects to different excitation frequencies, the estimation of delamination length and thickness position have remained insufficiently investigated [4]. The aim of this study is to correlate various parameters of single and multiple defects with the wave scattering behavior.

The interaction of waves with a layering whose length is greater than the wavelength leads to multiple reflections, and the superposition of several wave packets distorts the signal. Therefore, the amplitude of a wave packet cannot be determined separately. The sensitivity of the layering can also be determined from the scattering coefficients of the energy of the reflected and transmitted wave packets. The energy of a time-dependent signal, $f_s(t)$, is

$$E_s = \int_{t_a}^{t_b} \left| f_s(t) \right|^2 dt \, , \quad (1)$$

where E_s is the energy in the Lamb wave signal in the time interval $[t_a, t_b]$.

The characteristic dimensions of the delamination were determined from the resonance curves using a method based on wave propagation. The concept of resonance phenomena was used to determine the delamination length. At resonance in the volume of the laminar composite, the following condition is satisfied

$$\cosh(\beta_n l)\cos(\cos\beta_n l) - 1 = 0 \, , \quad (2)$$

where

$$\beta_n = \left[\omega_n^2 \rho A/(E I)\right]^{0.25} , \quad (3)$$

ω is the natural frequency of n-th mode; l is the length of delamination; E is the modulus of elasticity; I is the second area moment inertia.

For the case of a longer delamination length compared to the wavelength λ_n, the delamination length can be expressed as

$$l = n\lambda_n / 2 \, . \quad (4)$$

Summary and conclusions. Analysis of the calculation method results showed that for a single delamination, the wave characteristics in sub laminates depend on the delamination position along the depth of the composite sample. For the case when delamination occurs outside the mid-plane, the presence of a counter reflection from the defect with a strong change in the Lamb wave phase, as well as mode conversion, is characteristic. Delamination in the mid-plane dissipates less energy in the antisymmetric components of the Lamb wave compared to the case when delamination occurs outside the mid-plane. It is shown that antisymmetric directed wave packets are less sensitive to delamination. The interaction of the wave with the mechanical defect causes the vibration of the bulk of the laminated composite. Stronger vibration occurs when the excitation frequency coincides with the resonance frequency of the sample, which leads to greater energy trapping in the defect region, and the subsequent release of energy causes stronger reflection of Lamb waves.

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