2021 DSTA dys-ta.com
16th INTERNATIONAL CONFERENCE
Dynamical Systems – Theory and Applications
December 6-9, 2021, On-line

Impact of fiber orientation angle on the phase velocity of the fundamental elastic wave modes in composite plates of angle-ply configuration

MAREK BARSKI[1*], ADAM STAWIARSKI[2], PAWEŁ ROMANOWICZ[3], MARCIN AUGUSTYN[4]

1. Chair of Machine Design and Composite Structures; Cracow University of Technology [0000-0002-2247-5846]
2. Chair of Machine Design and Composite Structures; Cracow University of Technology [0000-0002-5700-4841]
3. Chair of Machine Design and Composite Structures; Cracow University of Technology [0000-0001-7475-1577]
4. Chair of Machine Design and Composite Structures; Cracow University of Technology [0000-0002-8023-9198]

* Presenting Author

Abstract: The present work is mainly devoted to the problem of the determination of the dispersion curves for the elastic waves, which propagate in the composite plates of angle-ply configuration. The plates are made of carbon fibers and epoxy resin. The dispersion curves are determined with the use of the stiffness matrix method. The specially dedicated software DisperseWin has been developed in C++. Next, the obtained values of phase and group velocity and corresponding values of the frequency are verified with the use of standard FE simulations. The elastic wave modes (symmetric and shear horizontal) are identified by applying the envelope method based on the Hilbert transform. It is observed that in the case of a simple box-shaped model of the piezoelectric elements (actuators) placed on the up and bottom surface of the plate and excited by the same signal, the symmetric and shear horizontal elastic wave modes are generated at the same time. In the case of some composite configurations, these modes are overlapped each other, and it is not possible to distinguish between them. Thus the special method of exciting the shear horizontal wave mode is proposed. A very good correlation between the values of group velocities obtained from the analytical calculation (dispersion curves) and the numerical simulation is observed.

Keywords: composite plates, fundamental elactic waves, dispersion curves, FE simulation**.**

1. Introduction

One of the very promising possibilities is the analysis of the phenomenon of the propagation of the elastic wave through the interrogated composite structure [1–3]. What more, this kind of damage detection system can be also implemented in the online mode and it can operate without the need of stopping the exploitation of the analyzed structure. These kinds of systems are known as structural health monitoring (SHM). However, the phenomenon of elastic wave propagation in composite structures possesses a very complex character. In the general case, the elastic wave consists of three different fundamental wave modes (symmetric S, anti-symmetric A, and shear horizontal SH) as is shown. Moreover, each mentioned fundamental wave mode together with increasing frequency possesses also higher modes. Some of these modes are very sensitive on the disperssion and some of them are almost not dispersive. These facts significantly complicates the proper interpretation of the registered dynamic resopnse of the analyzed structure in order to detect the potential damage.

Therefore, the very important part of the designing of the SHM systems, especially in the case of composite structures, is determining of the dispersion properties of the elastic waves.

2. Results and discussion

In the present work, the dispersion curves are determined for the laminate made of carbon fiber/epoxy resin (fibers T300, matrix N5208). The mechanical properties of the layers are as follows: E_1 = 181 GPa, E_2 = 10.3 GPa, G_{12} = 7.17 GPa, v_{12} = 0.28, and density ρ = 1.6 g/cm³. The laminate consists of 8 layers of identical thickness, where t_i = 0.25 mm. It is assumed that the studied laminate is of the angle-ply configuration, namely $[\pm\theta]_4$, where θ denotes the angle between the fibers in a particular layer and the X direction of the global coordinate system. In Figure 1 is presented the sets of dispersion curves, which are generated for the laminates where the fiber orientation angle is equal to θ = 0°. The assumed range of frequecy is 0.05 MHz < f < 1 MHz and corresponding range of phase velocity is 0.2 km/s < c < 12 km/s.

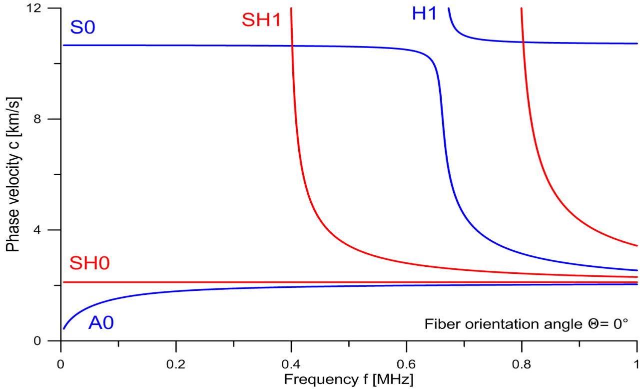

Fig. 1. Dispersion curves obtained for the carbon laminate of configuration $[\pm 0°]_4$

The following values of θ are studied, namely: θ=0°, 5°, 15°, … , 90°. The stiffness matrix method is applied. It should be stressed here that the this method occurred to be a very effective approach even in the case of composite materials with strongly anisotropic mechanical properties. To the contrary of the other matrix methods, this method is unconditionally numerically stable. The impact of the laminate configuration (in other words, the fiber orientation angle θ) can be summarized as follows:

- the phase c and group velocity c_g of the fundamental symmetric elastic wave mode S_0 monotonically decreasing;
- quite different behavior can be observed in the case of the fundamental shear horizontal mode SH_0. The clear maximum is found for the θ≈45°. Moreover, for the 55° < θ < 75° the phase velocity c as well as group velocity cg of the fundamental symmetric mode S_0 is much lower in comparison with the fundamental shear horizontal mode SH_0;
- the phase c and group velocity cg of the fundamental anti-symmetric wave mode A_0 decreases slightly together with increasing of the fiber orientation angle θ;
- the first higher elastic wave modes are observed for the frequency f≈400[kHz].

References

[1] Su Z, Ye L, Lu Y: Guided Lamb waves for identyfication of damage in composite structures. *Journal of Sound and Vibration* 2006,.**295**:753-780.

[2] Giurgiutiu V: *Structural Health Monitoring with Piezoelectric Wafer Active Sensors*. Elsevier, 2008.

[3] Zhongqing S, LIN Y: *Identyfication of damage using Lamb wavesok*. Springer-Verlag: Berlin, 2009.