Numerical study of the Time-of-Flight Pulsed Ultrasonic Polar Scan for the determination of the full elasticity tensor of orthotropic plates

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Abstract

A novel approach is presented for the ultrasonic determination of the elastic constants in plate-like structures of an orthotropic material (e.g. composites) using a time-of-flight version of the pulsed ultrasonic polar scan (TOF P-UPS). A forward numerical model of the TOF P-UPS is coupled to an inversion algorithm, based on the genetic optimization principle, targeting the determination of the orthotropic elastic parameters, and the quality of the inversion is demonstrated for synthetic data representative for composites. The advantage of the new approach is that the presented TOF P-UPS inversion method does not require a priori knowledge about the symmetry class of the material, nor about the orientation of the main axes of symmetry. Furthermore, the TOF P-UPS inversion method yields an accurate characterization of the orthotropic elasticity tensor, even when applied to composite plates with small frequency-thickness ratios in which the traditional bulk wave approaches no longer hold. Finally, the robustness of the TOF P-UPS inversion method is demonstrated for noisy data by evaluating the results for a range of signal-to-noise ratios.

Keywords: Ultrasonic Polar Scan, Time-of-Flight, NDT, characterization

1. Introduction

The last few decades experienced an exponential increase in the use of composite materials, such as carbon or glass fiber reinforced plastics (CFRP - GFRP). These composites typically have a low weight to high stiffness ratio, making them particularly interesting for application in aerospace structures and, more recently, in primary, load-bearing components. On the one hand, proper selection of the orientation of the reinforcement fibers leads to a directional mechanical response which may be tuned for a specific functionality, e.g. high stiffness in one direction. On the other hand, however, such a mechanical anisotropy makes it challenging to characterize composites in a straightforward manner. Though, in designing composite components it is of crucial importance to have knowledge on the stiffness tensor in order to assure the component's functionality and to maintain its structural integrity. In the past, several non-destructive characterization techniques have been proposed and developed to obtain information about the elastic material properties on the basis of ultrasound [1–6], in which most characterization techniques simply employ bulk wave concepts. Typically, these techniques rely on the Time-of-Flight (TOF) of an ultrasound pulse, from which the wave velocity can be determined, which is on its turn related to the mechanical stiffness of the investigated medium [1–8]. Although, these methods have proven their effectiveness, they also suffer from a number of drawbacks which are inherent to the use of bulk waves.

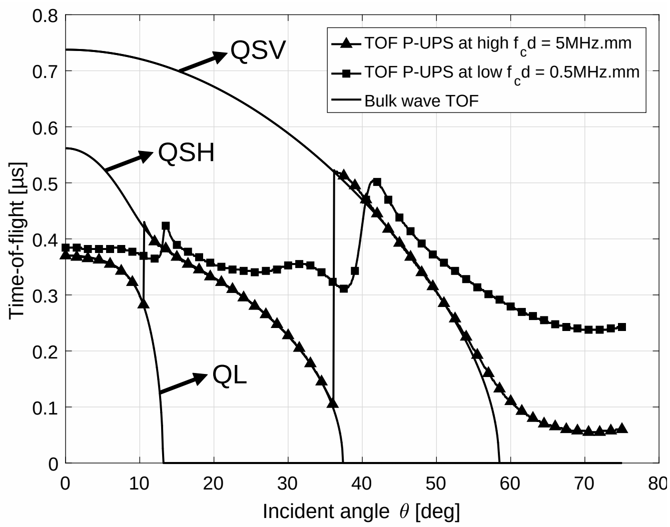

Figure 1: Cross-section (at azimuthal angle $\phi = 45°$) of the TOF P-UPS data for an artificial orthotropic material (cfr. column 3 of table 1) at different $f_c d$ values (triangle and square curves). The TOF results for bulk wave propagation (solid curve) for the same azimuthal angle are superimposed.

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