UDC 621.03

DISPERSION ANALYSIS OF GUIDED WAVES IN COMPOSITE STRUCTURES

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Abstract: Broadband guided waves are usually highly dispersed and multimodal, which is a good candidate for time-frequency analysis. In the time and frequency domain, the dispersion trajectory of a dispersive single-mode wave, which is a function of frequency, follows its frequency-dependent dispersion law. In order to effectively analyze such highly dispersed and multimodal broadband guided wave in composite structures, a generalized time-frequency analysis method based on wavelet transform was proposed in this study. This method includes a generalized wavelet transform and a mode separation procedure. The advantages of the proposed method include distinguishing and obtaining the dispersion trajectories of highly dispersed and overlapping modes of the highly dispersed and multimodal broadband guided wave in the time and frequency domain.

Key words: Composite materials, dispersion law, guided waves, time-frequency analysis, wavelet transform.

Guided waves, which are mechanical stress waves propagating in laminar composites guided by their boundaries, travel long distances with little energy loss [1]. This property allows for the wide application of guided waves in monitoring the bulk state of composites and non-destructive integrity assessment. The basic principle is that guided waves, passing through a different structure or region, which may also contain multiple defects, change their characteristics, such as amplitude, phase, dispersion, and time of flight. Dispersion and multimodality are two important properties of guided waves that are closely related to the structure of the laminar composite [2]. Dispersion affects the group velocity of guided waves, which changes with frequency. Multimodality indicates that guided waves have multiple modes, which differ based on the mode of propagation in the volume of the composite, i.e. symmetric and antisymmetric modes [3].

Narrowband and single-mode guided waves are generally not characterized by strong dispersion [4]. In particular, a narrowband wave packet with a selected center frequency is used as an excitation. In the detected guided wave signal, the mode of the wave packet is determined by estimating the arrival time of the wave packet center. The arrival time is estimated according to the theoretical dispersion curve of this mode at a fixed frequency. Both the energy and the arrival time of the identified wave packet are two critical quantities that are used to detect the defect.

In order to acquire the knowledge about the structure, the dispersion of guided waves have been modeled for various structures. The shortcomings of the dispersion analysis based on guided wave modeling are the different models have to be set up for different structures. Even for the same structure, the models could be different due to the material variation. It is difficult to construct models for complicated structures. The signal processing based dispersion analysis, on the other hand, provides a more straightforward solution for various structures and can be carried out for complicated structures.

In this paper, the broadband guided wave is described as the highly dispersive and multimodal broadband guided wave. The complexity of the highly dispersive and multimodal broadband guided wave makes it a good candidate for time–frequency analysis. For a broadband dispersive single-modal wave, the ridge in the time-frequency representation is called dispersion trajectory, which is an important time–frequency feature corresponding to the dispersion law of the wave. For the highly dispersive and multimodal broadband guided wave, ridges in the time-frequency representation is dispersion trajectories of different modes, each of which varies nonlinearly with the frequency and overlaps with others at certain frequency. The generalized wavelet transform was proposed for a non-stationary signal whose instantaneous frequency can be approximated by a Fourier series. In signal processing, instantaneous frequency and group delay are a pair of counter-concepts. The former means that frequency is a function of time, while the latter shows that time is a function of frequency. In this methodology, a continuously varying group delay with a dispersion trajectory was analyzed. The technique involves the use of a dual generalized wavelet transform in the frequency domain.

In this study, dual generalized wavelet transform in frequency and mode isolation is applied to analyze the dispersion pattern of highly dispersed and multimode broadband guided wave propagating in composite structures. The proposed method can effectively separate modes with intersecting dispersion paths and accurately characterize the highly nonlinear dispersion paths of different modes. For simulated Lamb waves, the proposed method outperforms the short-time Fourier transform.

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