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Calculation of guided wave interaction with nonlinearities and generation of harmonics in composite structures through a wave finite element method

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Abstract

The extensive usage of composite materials in modern industrial applications implies a great range of possible structural failure modes for which the structure has to be frequently and thoroughly inspected. Nonlinear guided wave inspection techniques have been continuously gaining attention during the last decade. This is primarily due to their sensitivity to very small sizes of localised damage. A number of complex transformation phenomena take place when an elastic wave impinges on a nonlinear segment, including the generation of higher and sub-harmonics. Moreover, the transmission and reflection coefficients of each wave type become amplitude dependent. In this work, a generic Finite Element (FE) based computational scheme is presented for quantifying guided wave interaction effects with Localised Structural Nonlinearities (LSN) within complex composite structures. Amplitude dependent guided wave reflection, transmission and conversion is computed through a Wave and Finite Element (WFE) method. The scheme couples wave propagation properties within linear structural waveguides to a LSN and is able to compute the generation of higher and sub-harmonics through a harmonic balance projection. A Newton-like iteration scheme is employed for solving the system of nonlinear differential equations. Numerical case studies are presented for waveguides coupled through a joint exhibiting nonlinear mechanical behaviour.

Keywords: Wave Interaction with Damage, Finite Elements, Composite Structures, Nonlinear Ultrasound, Structural nonlinearities

1. Introduction

Modern industrial structures are increasingly made of composite layered materials due to their well-known benefits. Composite structures may however exhibit a great variety of structural failure modes (including delamination, fibre breakage, matrix cracking and debonding) and must be frequently inspected in order to ensure continuous structural integrity. An increasing tendency within the Structural Health Monitoring (SHM) community is the 'shift to the left' maintenance strategy [1] for which the earliest possible detection of damage is important. When it comes to the aeronautical industry, approximately 27% of an average modern aircraft's lifecycle cost [2] is spent on inspection and repair. The use of 'offline' structural inspection techniques currently leads to a massive reduction of the

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