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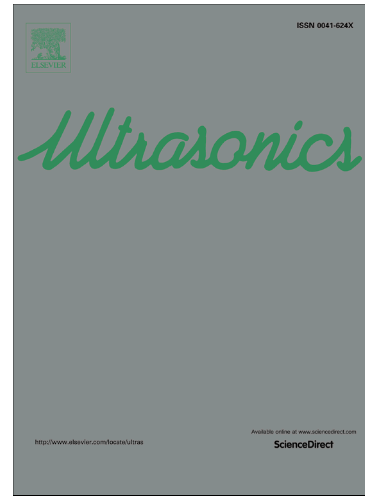

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Modeling of Nonlinear Interactions between Guided Waves and Fatigue Cracks Using Local Interaction Simulation Approach

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ABSTRACT

This article presents a parallel algorithm to model the nonlinear dynamic interactions between ultrasonic guided waves and fatigue cracks. The Local Interaction Simulation Approach (LISA) is further developed to capture the contact-impact clapping phenomena during the wave crack interactions based on the penalty method. Initial opening and closure distributions are considered to approximate the 3-D rough crack microscopic features. A Coulomb friction model is integrated to capture the stick-slip contact motions between the crack surfaces. The LISA procedure is parallelized via the Compute Unified Device Architecture (CUDA), which enables parallel computing on powerful graphic cards. The explicit contact formulation, the parallel algorithm, as well as the GPU-based implementation facilitate LISA's high computational efficiency over the conventional finite element method (FEM). This article starts with the theoretical formulation and numerical implementation of the proposed algorithm, followed by the solution behavior study and numerical verification against a commercial finite element code. Numerical case studies are conducted on Lamb wave interactions with fatigue cracks. Several nonlinear ultrasonic phenomena are addressed. The classical nonlinear higher harmonic and DC response are successfully captured. The nonlinear mode conversion at a through-thickness and a half-thickness fatigue crack is investigated. Threshold behaviors, induced by initial openings and closures of rough crack surfaces, are depicted by the proposed contact LISA model.

1 INTRODUCTION

Fatigue cracks may exist in a broad range of engineering materials and are considered precursors to catastrophic failures. Effective detection of fatigue cracks at their early stages is of critical importance and particular interest [1]. However, unlike gross damage, the fatigue cracks are barely visible in their closed state, imposing considerable difficulty for the conventional ultrasonic techniques which are only sensitive to open cracks [2]. On the other hand, nonlinear ultrasonic techniques have shown much higher sensitivity to incipient structural changes with distinctive nonlinear features, such as higher/sub harmonic generation, DC response, mixed frequency modulation response (sideband effects), and various frequency/amplitude dependent threshold behaviors [3, 4]. The integration of nonlinear ultrasonic techniques into guided wave based interrogation procedures is drawing increasing attention from the Structural Health Monitoring (SHM) and Non-destructive Evaluation (NDE) communities, because such a practice inherits both the sensitivity from nonlinear NDE techniques and the large-area inspection capability from SHM guided waves [5].

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