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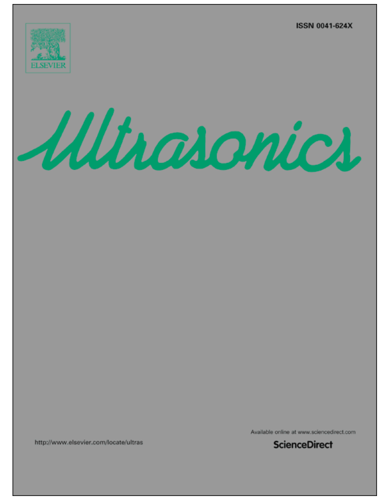


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Ehsan Dehghan-Niri, Helem Al-Beer

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# Phase-space topography characterization of nonlinear ultrasound waveforms

Ehsan Dehghan-Niri[1*], and Helem Al-Beer[1]
[1] Civil Engineering Department, New Mexico State University (NMSU), USA
[*]Phone: +1 575 646 3514; e-mail: niri@nmsu.edu

**Abstract:**

Fundamental understanding of ultrasound interaction with material discontinuities having closed interfaces has many engineering applications such as nondestructive evaluation of defects like kissing bonds and cracks in critical structural and mechanical components. In this paper, to analyze the acoustic field nonlinearities due to defects with closed interfaces, the use of a common technique in nonlinear physics, based on a phase-space topography construction of ultrasound waveform, is proposed. The central idea is to complement the "*time*" and "*frequency*" domain analyses with the "*phase-space*" domain analysis of nonlinear ultrasound waveforms. A nonlinear time series method known as pseudo phase-space topography construction is used to construct equivalent phase-space portrait of measured ultrasound waveforms. Several nonlinear models are considered to numerically simulate nonlinear ultrasound waveforms. The phase-space response of the simulated waveforms is shown to provide different topographic information, while the frequency domain shows similar spectral behavior. Thus, model classification can be substantially enhanced in the phase-space domain. Experimental results on high strength aluminum samples show that the phase-space transformation provides a unique detection and classification capabilities. The Poincaré map of the phase-space domain is also used to better understand the nonlinear behavior of ultrasound waveforms. It is shown that the analysis of ultrasound nonlinearities is more convenient and informative in the phase-space domain than in the frequency domain.

**Keywords:** nonlinear ultrasound, cracks, kissing bond, phase-space, Poincaré map, pseudo phase-space, frequency domain, time domain.

## 1. Introduction

To address the world's aging infrastructure such as bridges, pipelines, power plants, and aircrafts, reliable test methods are needed to detect and characterize defects with closed interfaces. Closed defects or lack of bond interfaces such as loaded fatigue cracks are often undetectable and are one of the main causes of failure in aging infrastructure. Traditionally, engineers and infrastructure practitioners routinely use different nondestructive testing (NDT) methods to evaluate materials' integrity of critical structural components to maintain the serviceability of infrastructures. In addition to the infrastructure aging problem, the new generation of materials and manufacturing processes – like additive manufacturing (AM) –