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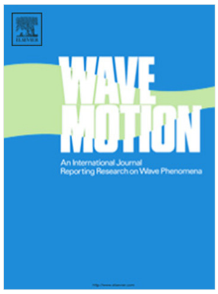

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Acoustic Diode: Wave Non-reciprocity in Nonlinearly Coupled Waveguides

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Abstract

The paper describes a passive time-independent setting for non-reciprocal wave transmission in mechanical and acoustic systems with strong nonlinearities. In the proposed system vibro-impact elements with predefined clearances are used to couple two non-dispersive waveguides. The asymmetry necessary for the non-reciprocal behavior is realized through unequal grounding springs of the vibro-impact elements. We show that, for appropriate selection of the parameters, the proposed system acts as a mechanical diode, allowing the transmission of acoustic waves in one direction and completely preventing reverse transmission. Two different designs of the coupling elements are suggested, with the possibility of single-sided or double-sided impacts. A unique feature of the proposed non-reciprocal acoustic system is that minimal distortion of the harmonic content of the transmitted wave occurs, in contrast to current designs where nonlinear non-reciprocity is achieved at the expense of a rather strong distortion of the transmitted signals. For both designs, we derive exact solutions for propagation and reflection of the harmonic waves, and demonstrate the possibility for strong non-reciprocity. Stability properties of the observed solutions in the space of parameters are also explored.

Keywords: non-reciprocity, acoustic diode, phonon diode, vibro-impact
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1. Introduction

Reciprocity in the context of dynamical systems refers to symmetrical wave transition between two points in the structure. Well-known classical results [1, 2, 3] demonstrate that linear time-invariant (LTI) systems governed by self-ajoint operators exhibit the reciprocal behavior. Such systems,as well as the linear systems in much broader context, obey the Betti-Maxwell reciprocity theorem. Dynamic and/or acoustic reciprocity in the LTI systems, in accordance with the famous Casimir-Onsager principle of microscopic reversibility [4, 5, 6] is directly related to time-reversal symmetry.

Most well-known ways to violate the reciprocity while preserving the linearity of the system are related to introducing odd-symmetric external biases, e.g., static magnetic fields [7], or uni-rotational fluid circulations [8, 9]. The other approach is to break the time invariance and to use models with time-variant properties. Typical, but by far non-exhaustive examples, are, e.g., coupled acoustic cavities with modulated volumes [10] or active metamaterials [11].

The other possible approach is to violate the assumption of linearity, and to consider globally or locally nonlinear structures. Examples based on properties of the nonlinear lattices are discussed in [12, 13]. A number of recent works considered various possible realizations for acoustic (phonon) diodes [14, 15, 16, 17, 18, 19, 20, 21]. Current nonlinear non-reciprocal designs cause significant alteration and distortion of the frequency content of the transmitted acoustic signal. In this work we provide a new, simple, yet highly

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