Experimental Study of Nonreciprocal Acoustic Energy Transfer in an Asymmetric Nonlinear Vibro-Acoustic System

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Abstract. An asymmetric and nonreciprocal vibro-acoustic system consists of a waveguide, three acoustic cavities with different sizes, and a strongly nonlinear membrane has been modelled, simulated, and experimentally demonstrated. The nonreciprocal transmission of acoustic energy in this prototype system is studied. Under forward excitation, internal resonance between the two nonlinear normal modes of the vibro-acoustic system occurs, and acoustic energy is efficiently and irreversibly transferred from the waveguide to the nonlinear membrane. However, under backward excitation, there is no internal resonance in the system. Consequently, the acoustic energy transfer of the system exhibits "giant nonreciprocity", i.e., nearly unidirectional (preferential) transmission of acoustic energy. The theoretical model of the system is verified by experiment, and parametric analysis is also carried out. Wavelet analysis and energy spectra are employed to highlight the mechanism of nonreciprocal transfer of acoustic energy.

Introduction

A nonlinear acoustic system[1] has a characteristic that its linear counterpart does not have, such as bifurcation or an energy-dependent resonant frequency, and so it can realize large nonreciprocal transmission of acoustic energy. Vakakis et al.[2] designed a series of nonlinear mechanical systems to achieve nonreciprocal energy transfer based on the nonlinear energy sink mechanism. Cochelin et al.[3] studied the phenomenon of targeted energy transfer in vibro-acoustic systems. However, there has been no quantitative, experimental study on asymmetric transmission of acoustic waves in those strongly nonlinear systems.

In this paper, a strongly nonlinear nonreciprocal vibro-acoustic system is constructed by adding a cavity on the opposite side of the membrane. The resulting system comprises a waveguide, three different size cavities, and a strongly nonlinear membrane. The two-degree-of-freedom model used to derive and simulate the governing equations of the system under forward and backward excitations were developed under the assumptions of a one-dimensional waveguide, von Karman shell theory, and low-frequency approximations for the acoustics in the cavities.

The nonreciprocal transfer of acoustic energy is realized by using different interaction mechanisms between nonlinear normal modes of the system under forward and backward excitations. The experimental results agreed well with the theoretical predictions, validating the discrete model and the system identification of its parameters; the discrete model could then be used with confidence to elucidate the governing nonlinear acoustics yielding nonreciprocity in the response of the system. The experimental and simulation data were further analyzed using wavelet analysis, energy spectra and other computational tools. The results reported herein contribute to practical designs of vibro-acoustic systems having the capacity of nonreciprocal, i.e., unidirectional, sound transmission.

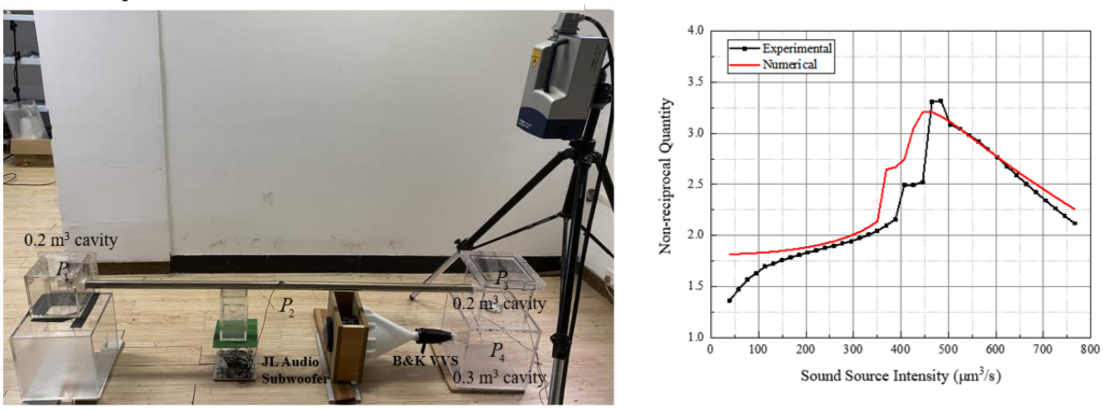

Figure 1: Nonreciprocal vibro-acoustic system (left) experimental set-up (right)comparison between experiment and simulation results of nonreciprocal measure.

References

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