Journal of Sound and Vibration 424 (2018) 224–237

Contents lists available at ScienceDirect

Journal of Sound and Vibration

journal homepage: www.elsevier.com/locate/jsvi

Experimental study of a hybrid electro-acoustic nonlinear membrane absorber

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ARTICLE INFO

Article history:
Received 27 October 2017
Revised 6 March 2018
Accepted 13 March 2018
Available online XXX

Keywords:
Noise reduction
Hybrid absorber
Nonlinear energy sink
Electroacoustic absorber
High sound level
Low frequency

ABSTRACT

A hybrid electro-acoustic nonlinear membrane absorber working as a nonlinear energy sink (here after named EA-NES) is described. The device is composed of a thin circular visco-elastic membrane working as an essentially cubic oscillator. One face of the membrane is coupled to the acoustic field to be reduced and the other face is enclosed. The enclosure includes a loudspeaker for the control of the acoustic pressure felt by the rear face of the membrane through proportional feedback control. An experimental set-up has been developed where the EA-NES is weakly coupled to a linear acoustic system. The linear acoustic system is an open-ended tube, coupled on one side to the EA-NES by a box, and on the other side to a source loudspeaker by another box. Only sinusoidal forcing is considered. It is shown that the EA-NES is able to perform resonance capture with the acoustic field, resulting in noise reduction by targeted energy transfer, and to operate in a large frequency band, tuning itself passively to any linear system. We demonstrate the ability of the feedback gain defining the active loop to modify the resonance frequency of the EA-NES, which is a key factor to tune the triggering threshold of energy pumping. The novelty of this work is to use active control combined to passive nonlinear transfer energy to improve it. In this paper, only experimental results are analyzed.

1. Introduction

The reduction of noise and vibration at low frequencies is still nowadays a main issue in many fields of engineering. In order to overpass this issue, a new concept of absorbers including nonlinear behavior has been developed in the past decade. This type of absorbers is based on the principle of the “Targeted Energy Transfer” (TET) also named “energy pumping” [1]. TET is an irreversible transfer of the vibrational energy from an input subsystem to a nonlinear attachment (the absorber) called Nonlinear Energy Sink (NES). TET permits to reduce undesirable large vibration amplitudes of structures or acoustic modes. Nonlinear energy transfer results from nonlinear mode bifurcations, or through spatial energy localization by formation of nonlinear normal modes. The phenomena can be described as a 1:1 resonance capture [2] and, considering harmonic forcing, as response regimes characterized in terms of periodic and Strongly Modulated Responses (SMR) [3].

The basic NES generally consists of a lightmass, an essentially nonlinear spring and a viscous linear damper. In the field of structural vibration, a wide variety of NES designs with different types of stiffness (cubic, non-polynomial, non-smooth nonlinearities ...) has been proposed [4–7]. In the acoustic field, to the best of our knowledge only one type of vibro-acoustic NES

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https://doi.org/10.1016/j.jsv.2018.03.014

design has been tested, see the series of papers [8–12]. It was demonstrated that a passive control of sound at low frequency can be achieved using a vibroacoustic coupling between the acoustic field (the primary system) and a geometrically nonlinear thin clamped structure (the NES). In Refs. [8,9,12], the thin baffled structure consists of a simple thin circular latex (visco-elastic) membrane whereas in Ref. [10] a loudspeaker used as a suspended piston is considered. In both cases, the thin baffled structure has to be part of the frontier of the closed acoustic domain (to be controlled). Hence only one face (named the front face) is exposed to the acoustic field whereas the other face (the rear face) radiates outside. Hence this type of devices has to be modified to be used in cavity noise reduction.

A simple way to do this is to enclose the rear face of the thin clamped structure limiting the sound radiation. This principle has been used to design electroacoustic absorbers based on the use of an enclosed loudspeaker including an electric load that shunts the loudspeaker electrical terminals [13]. An electroacoustic absorber can either be passive or active in terms of their noise suppression characteristics including as in Refs. [14,15] pressure and/or velocity feedback techniques. Loudspeakers have also been used to design devices to control normal surface impedance [16]. Two approaches have been developed. The first is referred to as direct control: the acoustic pressure is measured close to the diaphragm of the loudspeaker and used to produce the desired impedance. In the second approach, passive and active means are combined: the rear face of a porous layer is actively controlled so as to make the front face normal impedance take a prescribed value.

In this paper, a hybrid passive/active nonlinear absorber is developed. The absorber is composed of a clamped thin circular visco-elastic membrane with its rear face enclosed. The acoustic field inside the hood (i.e the acoustic load of the rear face) is controlled using a loudspeaker with proportional feedback control. Three objective are assigned. Firstly, the device has to be designed such that it can be used inside a cavity. Secondly, noise reduction must mainly result from TET due to the nonlinear behavior of the membrane, thus defining a new concept of NES. Thirdly, the control loudspeaker has to be used as a linear electroacoustic absorber inside the hood. The control loudspeaker does not act directly on the acoustic field to be reduced. It only modifies the relative acoustic load exciting the membrane. This absorber is here after named hybrid electroacoustic NES (EA-NES).

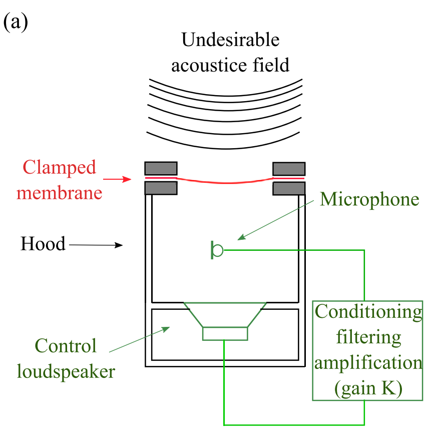
The paper is organized as follows. In Section 2, the principle of functioning of the EA-NES under study is described considering each sub-structure separately. In Section 3, we first describe the experimental set-up. It is composed of an acoustic field (in a pipe, excited by a loudspeaker) coupled to the EA-NES. Then we check the stability analysis of the feedback loop and perform a frequency analysis under broadband excitation. In Section 4, we analyze in detail the responses under sinusoidal excitations and we bring some confirmations on the efficiency of the EA-NES.

2. The hybrid electro-acoustic NES

2.1. General presentation

The EA-NES is shown in Fig. 1. It is composed of a clamped circular latex membrane with one face (the front face) exposed to the acoustic field to be reduced and the other one (the rear face) enclosed. The hood includes a feedback loop composed of a microphone, a loudspeaker and a unit control. The feedback loop controls the acoustic pressure inside the hood and seen by the rear face of the membrane.

The EA-NES is based on the conjugate functioning of three elements:



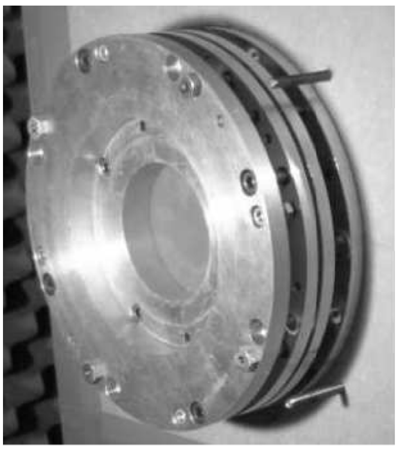


Fig. 1. EA-NES: (a) Schematic representation and (b) Front face.