Journal of Sound and Vibration 400 (2017) 288–304

Contents lists available at ScienceDirect

Journal of Sound and Vibration

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

Smart panel with time-varying shunted piezoelectric patch absorbers for broadband vibration control

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ARTICLE INFO

Article history:
Received 1 September 2016
Received in revised form
22 February 2017
Accepted 5 April 2017
Handling Editor: D.J. Wagg

Keywords:
Switching control
Sweeping control
Piezoelectric shunted absorber
Piezoelectric transducer
Tuned vibration absorber
Dynamic absorber
Vibration control

ABSTRACT

This paper presents a simulation study concerning the low and mid frequencies control of flexural vibration in a lightly damped thin plate equipped with five time-varying shunted piezoelectric patch absorbers. The panel is excited by a rain-on-the-roof broad frequency band stationary disturbance. The absorbers are composed by piezoelectric patches connected to time-varying RL shunt circuits. Discrete or continuous variations over time of the shunts are implemented in such a way as to either switch, between given values, or sweep, within certain ranges, the natural frequency and damping factor of the electro-mechanical absorbers to control either the resonant response of targeted flexural modes of the plate with natural frequency comprised between 30 Hz and 1 kHz or to control the resonant responses of all flexural modes with natural frequencies comprised between 30 Hz and 1 kHz. The proposed system is firstly presented; then, the vibration control effects produced by a single patch and by the array of five patches implementing the switching and sweeping shunts are investigated. Both time-varying operation modes produce significant vibration control effects, with reductions of the resonance peaks of the target resonances or target frequency band up to 12 dB. The piezoelectric patch absorbers with sweeping shunts offer an interesting practical solution since they are operated blindly, thus they do not require a system identification during installation and effectively work without on line tuning also on systems whose response may vary substantially in time.

1. Introduction

Forward [1] was one of the first to propose in 1979 the use of shunted piezoelectric transducers to control the vibration of structures. In the following years, several studies were published on this topic [2–9], which investigated the basic principles of vibration control with shunted piezoelectric transducers. While references [10–12] offer detailed reviews on this subjects as well as the comprehensive book by Moheimani and Fleming [13], the specific idea of implementing electro-mechanical vibration absorbers using piezoelectric patches connected to RL shunt circuits can be traced to the seminal study carried out by Hagood and von Flotow [5]. In this work they observed how the capacitive effect of the piezoelectric patch combined with a RL shunt gives rise to a RLC resonating electrical circuit whose resonance frequency and damping factor can be tuned to maximise the conversion and absorption of vibration energy of the hosting structure via the piezoelectric transduction effect. Considering the classical work on vibration absorbers [14], they derived the expressions for the

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http://dx.doi.org/10.1016/j.jsv.2017.04.012
0022-460X/

resistance and inductance elements of the shunt that would optimise the vibration absorption effect at the resonance frequency of a specific natural mode of the structure with the shunted piezoelectric patch. In general both series and parallel RL shunts can be used to produce the electro-mechanical vibration absorption effects [5,15], although the parallel configuration allows the independent tuning of the shunt resonance frequency and internal damping by varying respectively the inductance and resistance of the shunt. As discussed in Refs. [16–19], for example, the vibration absorption produced by the shunted piezoelectric patches can be enhanced by adding a negative capacitance effect in the shunt (normally synthetized with an active circuit), which reduces the inherent capacitance of the piezoelectric transducer. Nevertheless, a piezoelectric patch connected to a classical RL or RLC shunt can suppress the resonant response of a specific natural mode of the hosting structure only. Multi-resonant shunt circuits were therefore investigated and developed to extend the control effect over multiple natural modes of the hosting structure [6,20–27], which however may require rather large inductance elements or active circuits to generate virtual inductors [22,25]. This study proposes an alternative solution with a classical RL shunt, whose resistance and inductance components are either switched, between given values, or swept, within certain ranges, in such a way as the resonance frequency and damping factor of the shunted piezoelectric patch absorbers are either cyclically tuned to control the resonant response of targeted flexural modes of the hosting structure with resonance frequencies comprised between 30 Hz and 1 kHz or continuously varied to control the resonant responses of all flexural modes of the hosting structure with resonance frequencies comprised between 30 Hz and 1 kHz. The sweeping operation mode offers the advantage that no specific tuning of the RL shunt is required and thus the system can be operated without needing system identification of the smart structure or on line tuning. As a result, the system is expected to work also on structures characterised by significant variations of the response due to changes in the operation conditions (e.g. large temperature variations, substantial tensioning effects, etc.).

The possibility of controlling the flexural response of thin structures over a wide frequency band using time-varying mechanical absorbers composed by classical spring-damper-mass systems was explored in recent studies [28–30]. In this work, an early version of which was presented in reference [31], the effects produced by switching and sweeping time-varying shunted piezoelectric patch absorbers bonded on a thin plate are considered. The study first introduces the details of the variational formulation for the flexural response of the plate equipped with one or five piezoelectric patch transducers connected to time-varying parallel RL shunts. Also, it provides a comprehensive account of the time-domain and of the frequency-domain numerical approaches used to derive and depict the cycle-stationary flexural response when the plate equipped with the time-varying shunted piezoelectric patches is exposed to rain-on-the-roof stochastic disturbance. It then revises the optimal tuning of the RL shunt components based on a single-mode model for the plate flexural response. Finally it presents and discusses in details the vibration control effects produced by series/parallel switching and series/parallel sweeping operation modes. This analysis is carried out considering the Power Spectral Density (PSD) of the plate total flexural kinetic energy in a wide frequency band comprised between 20 and 1400 Hz. In this way it was possible to assess both the control performance up to 1 kHz and the development of control spillover effects beyond 1 kHz.

The paper is structured in five sections. Section 2 describes the smart panel with time-varying shunted piezoelectric patches. Also it introduces the mathematical model and the state-space and spectral formulations used to derive and depict the flexural response when the panel equipped with the shunted piezoelectric patch absorbers is excited by a rain-on-the-roof broad band disturbance. Finally, it provides a brief description of the approach used to select the shunt resistive and inductive components for the fix tuning and switching operation mode. Section 3 investigates the vibration control effects that would be produced by a single piezoelectric patch with a classical fix tuning shunt or with the proposed switching and sweeping shunts. Then, Section 4 contrasts the vibration control effects produced by five shunted piezoelectric patch absorbers that implement either fix tuning shunts or series/parallel switching/sweeping shunts. Finally, Section 5 summarises the principal conclusions of the study.

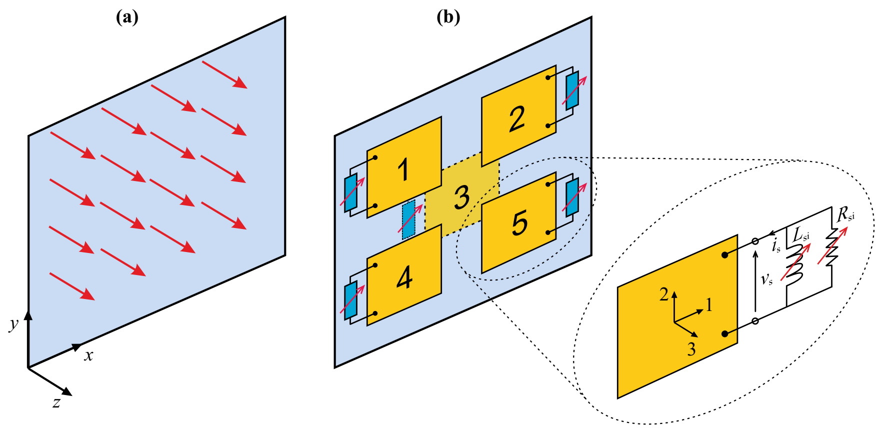

Fig. 1. Plate subject to a rain-on-the-roof excitation modelled with a 4×4 array of uncorrelated point forces (a) and equipped with five piezoelectric patches connected to time-varying RL shunts (b).