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Review

# Vibration and noise control using shunted piezoelectric transducers: A review

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A B S T R A C T

Among various strategies developed for the attenuation of noise and vibration in mechanical structures, piezoelectric shunt damping, which consists in connecting piezoelectric transducers integrated in a structure to electric or electronic circuits, is a promising alternative for use in small- and mid-scale structural components. Despite the fact that the shunt damping technology has been investigated for quite a long time, it is recognized that its application to real-world structures still requires developments aiming at improving its effectiveness and range of application under unavoidable practical constraints. As a result, research on improved solutions related to piezoelectric shunt damping is still very active. Due to the very nature of the piezoelectric shunt damping, it becomes clear that further improvements must consider both mechanical and electrical/electronic aspects. Based on the current state-of-the-art, this paper provides a systematic literature review of different piezoelectric shunt damping strategies developed for the attenuation of vibration and noise in mechanical systems, including an assessment of the basic principles underlying the electromechanical behavior, as well as design procedures and numerical modeling of piezoelectric shunt damping devices applied to elastic vibrating systems. Emphasis is placed on the various types of shunt circuits, including the traditional passive resonant circuits, multimode resonant circuits, adaptive tuning circuits, switching circuits, and negative capacitance. The strategies for location and shape of the piezoelectric transducers is also discussed. A variety of applications recently reported in the scientific literature and in patents are presented. An assessment is made about more significant recent achievements and technological issues to be faced in further developments.



**Contents**



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## 1. Introduction

It is widely known that mechanical structures of various types, including ground, water and air vehicles, industrial equipment and civil constructions are very often subjected to vibrations induced by operational or environmental effects, which can be detrimental, causing discomfort of operators and passengers, leading to wear and fatigue of mechanical components, and generating noise. The ultimate consequences can vary from economic loss to risk of catastrophic events.

Over decades, a variety of active, passive and hybrid techniques intended for tackling problems of noise and vibration control of structures have been developed and acquired considerable degree of maturity [1]. However, current trend towards lightweight structures, as a direct consequence of the ever increasing demand for more efficient and environmentally friendly structures, leads to new challenges on vibration control technology. One particular challenge is to ensure attenuation efficiency in large frequency bands, most frequently under constraints imposed on energy consumption, added weight, and installation and operation costs. As a result, new solutions are constantly been sought.

In this context, the emergence of the so-called smart materials has unscreened new routes for innovative solutions. According to Leo [2], those materials are characterized by the existence of coupling between different physical domains (mechanical, thermal, electrical, chemical) in such a way that the state variables related to a given domain can be modified in response to changes in the state variables of another domain. In the realm of mechanical systems, such a coupling can be explored for the design of displacement or strain sensors and force or motion generators (actuators).

The most widely known smart materials and respective underlying coupling are piezoelectric materials (electro-mechanical coupling), shape-memory alloys (thermal–mechanical coupling), electroactive polymers (electro-mechanical coupling), and electro-rheological fluids (electro-mechanical coupling) magneto-rheological fluids (magnetic-mechanical coupling).

Among the smart materials of practical interest, piezoelectric materials, which are focused in this paper, are undoubtedly the most mature and those with the most widespread applications. In fact, those materials can be used for both sensing and actuation, and can be found with a broad range of mechanical characteristics, ranging from very stiff and dense ceramics to highly flexible and light polymers. Additionally, they can operate in a wide frequency range.

Piezoelectricity is the property exhibited by some natural and synthetic dielectric materials, which develop surface distributions of electric charges when they are subjected to mechanical loads (direct piezoelectric effect) and, conversely, suffer geometric or dimensional changes when subjected to external electrical fields (converse piezoelectric effect) [3–5]. Considering that a piezoelectric element is mechanically connected to a given structure, the direct effect is explored as the basis of dynamic strain sensors, whilst the functioning of piezoelectric actuators relies on the converse effect.

Significant piezoelectric effect can be observed in polycrystalline ferroelectric ceramics such as lead zirconate titanate (PZT) or barium titanate ($BaTiO_3$) and polymers such as polyvinylidene fluoride (PVDF), which are the most widely used in practical applications [6–9].

For the purpose of noise and vibration control, piezoelectric materials have been used as physical components of active and passive control systems. For the first, they can be used either as sensors or actuators in a control loop such as depicted in

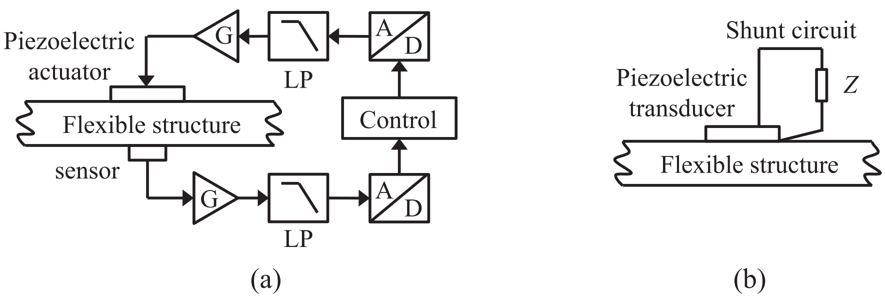


**Fig. 1.** Some vibration control techniques. (a) active vibration control, (b) piezoelectric shunt damping.