The use of negative capacitances to improve the vibration attenuation of piezoelectric resonant shunt

Marta Berardengo*+, Stefano Manzoni†, Olivier Thomasº and Marcello Vanali+

+ Università degli studi di Parma - Department of Engineering and Architecture
Parco Area delle Scienze, 181/A – 43124 Parma, Italy
Email: marta.berardengo@unipr.it, marcello.vanali@unipr.it

† Politecnico di Milano – Department of Mechanical Engineering
Via La Masa, 34 – 20156 Milan, Italy
Email: stefano.manzoni@polimi.it

º Arts et Métiers ParisTech, LSIS UMR CNRS 7296
8 bd. Louis XIV 59046 Lille, France
Email: Olivier.THOMAS@ensam.eu

ABSTRACT

The use of shunted piezoelectric actuators is really promising in the field of vibration mitigation in light structures. This approach relies on the connection between a properly designed electric impedance [1] and a piezoelectric actuator bonded to the vibrating structure. Several works are already available in the literature, describing how to shunt piezoelectric actuators (both benders and stacks) and achieve high damping performances. One possibility to increase these damping performances is the use of negative capacitances (NC) in the shunt circuit.

Even if the use of NCs is already proved to be highly effective and reliable, a comprehensive analysis of this control approach is missing in the literature. Particularly, the use of resonant shunts (i.e. shunts where the electric impedance is made from a resistance and an inductance connected in either series or parallel) coupled to NCs is not deeply treated. Since this layout of the shunt impedance (i.e. resonant shunt coupled to NCs) offers high damping performances [2], this paper is specifically addressed to derive optimization formulas for this type of shunt. This allows to design optimal shunt impedances, as well as to foresee the consequent expected level of vibration attenuation.

Moreover, this study also allows to compare different layouts of the shunt impedance, finding which one is the best in given engineering applications. Indeed, the combination of a resonant impedance and NCs can have six different layouts because the inductance and the resistance can be linked in either series or parallel, and the NCs can be connected to the piezoelectric actuator in three different ways: series, parallel, and the newly introduced series+parallel [3].

The paper first describes the theoretical model used to describe the dynamic behaviour of the electromechanical structure. Then, the procedure used to optimize the shunt impedance is discussed, together with the achieved analytical results. This means that optimisation formulas are provided, together with formulations to predict the vibration attenuation. Finally, an experimental campaign is presented in order to validate all the discussed theoretical results. Furthermore, the paper also addresses problems which can be encountered in the practical implementation of NCs coupled to resonant shunt, and explains how to solve them or limit their effects.

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