A Simplified Current Blocking Piezoelectric Shunt Circuit for Multimodal Vibration Mitigation

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ABSTRACT
This paper presents a novel arrangement of a current blocking shunt circuit for the mitigation of multiple structural resonances. The number of required electrical components is reduced compared to the previous versions of this circuit proposed in the literature. This paper also proposes a tuning methodology for the electrical parameters of this circuit based on the evaluation of the electromechanical coupling between the electrical circuit and the structure. Effective mitigation performance can be expected with little knowledge of the host structure. A comparison with the solutions in the literature demonstrates the efficiency of the proposed approach.

Keywords: Piezoelectric absorber, Multimodal damping, Passive control, Two-port network

INTRODUCTION

Piezoelectric shunt damping terms a mean by which a piezoelectric transducer mechanically connected to a host structure is used to mitigate the vibratory amplitude of this structure. Thanks to the direct piezoelectric effect, a part of the mechanical energy of the vibrating structure is transformed into electrical energy by the transducer. This energy can efficiently be dissipated with the help of a shunt circuit, usually composed of an inductor and a resistor arranged either in series [1] or in parallel [2]. Hence, piezoelectric shunt damping can be used to mitigate the vibratory amplitude of a resonance of a structure.

One of the advantage of piezoelectric shunt damping is the possibility to passively control multiple structural modes if the electrical circuit is properly designed. A number of ad-hoc circuits aimed at multiple mode shunt damping can be found in the literature. The current blocking shunt circuit proposed by Wu [3] and the current flowing shunt circuit proposed by Behrens et al [4] are well-known examples of such circuits. The former is efficient but requires a large number of electrical components to be implemented. The latter requires less electrical components but it has been shown by Cigada et al [5] that tuning this circuit results from a tradeoff between damping performance and tuning easiness.

The purpose of this paper is to present a new simplified current blocking shunt circuit for the mitigation of multiple structural resonances and to provide and associated tuning methodology. This circuit does not suffer from the same tradeoffs as the current flowing shunt circuit, and generally requires less electrical components than the arrangements of the current blocking circuit proposed in the literature.

SIMPLIFIED CURRENT BLOCKING SHUNT CIRCUIT

A new arrangement for the current blocking circuit is presented in Fig. **1**. This circuit consists in a periodic repetition of a current blocking filter (parallel LC circuit) and a shunt branch (series RL or parallel RL branch, generically represented as $Z_{s,i}$, $i = 1, \dots, N$ in Fig. **1**). Each branch is tuned to a specific resonance frequency. The impedance of a shunt branch generally decreases with increasing frequency of the structural mode it is tuned to. At a given frequency, the branches tuned to a higher structural frequency appear nearly as a short circuit compared to the branch of interest. To prevent current from bypassing this branch, the access to the lower-impedance branches is forbidden by a current blocking filter. At the frequency of interest, this filter has an infinitely high impedance which rapidly decreases away from this frequency. If the shunt branches are arranged in ascending order of structural frequencies they are tuned to, this shunt circuit can act like a classical single-mode shunt circuit at multiple resonance frequencies.

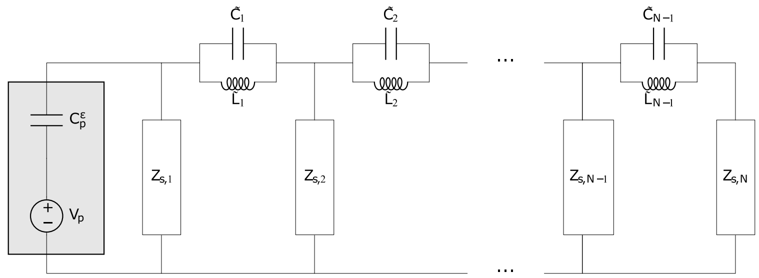

Fig. 1 A simplified current blocking shunt circuit to control N structural frequencies.

Compared to the original current blocking shunt circuit and its modified version proposed by Wu [3], the simplified current blocking shunt circuit has the advantage of requiring a number of electrical components that grows linearly with respect to the number of modes to be controlled (whereas this growth is quadratic in [3]).

TUNING METHODOLOGY

This section proposes a tuning methodology that is based on the knowledge of the electromechanical coupling between the piezoelectric transducer and the structure (through the resonance frequencies when the electrodes of the piezoelectric transducer are short-circuited and open-circuited) and the electrical parameters (including the piezoelectric capacitance at constant strain). For each shunt branch, an optimal impedance is computed from the single-mode shunt formulas available in the literature (in this paper, the formulas in [6] are used for series RL shunt circuits and the formulas in [2] are used for parallel RL shunt circuits).

The methodology is divided into several steps in which each shunt branch and its associated current blocking filter are tuned. Since the impedance of the current blocking filter is very high at the frequency of interest, the electrical elements placed after it (to its right in Fig. **1**) may be neglected, i.e. approximated as a short circuit. This way, thanks to the current blocking filters, the shunt branches and associated current blocking filters can be tuned sequentially in ascending order. At a given step of the methodology, there are no other unknowns than the ones related to the structural mode of interest. The capacitance of the filter is left as a degree of freedom in the design. The inductance of the filter is simply determined by requiring that the resonance frequency of the filter be equal to the considered structural resonance frequency. Finally, the resistance and inductance of the shunt branch are tuned according to the method explained hereafter.

The tuning problem of a shunt branch can be modelled in a general way by abstracting the surrounding electrical network as a two-port network. One port is connected to the shunt branch and the other is connected to the piezoelectric transducer. To simplify the problem, the electrical characteristics of the piezoelectric transducer and of the two-port network are first reduced to an RLC circuit. The capacitance of this reduced circuit is used to assess the electromechanical coupling between the shunt branch and the structure, based on the electromechanical coupling of the piezoelectric transducer and the structure. An optimal impedance can then be computed using single-mode shunt formulas from the literature. The resistance and inductance of the shunt branch are finally determined by requiring that their combination with the resistance and inductance of the reduced circuit be an impedance equal to the optimal impedance.

The proposed tuning methodology is simple and requires the knowledge of a limited number of parameters of the electromechanical system. These parameters are relatively easy to obtain either numerically or experimentally. It yields satisfactory performance without the need for costly numerical optimization algorithms. Fig. **2** illustrates this statement with a two-degree-of-freedom spring mass system to which a piezoelectric transducer is attached. This piezoelectric transducer is then connected to a current blocking shunt circuit. The filter capacitance is chosen in each case equal to the piezoelectric capacitance at constant strain. The amplitudes of the two structural modes are reduced using either series or parallel shunt branches. An improvement in performance can be observed with the new tuning methodology, especially on mode 2.

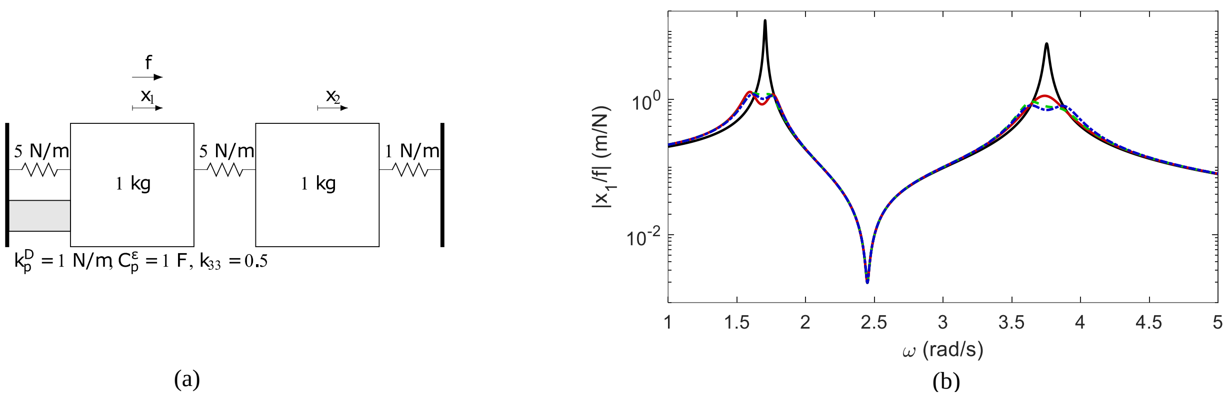

Fig. 2 Considered two-degree-of-freedom system (a) and corresponding frequency response function (b): open-circuit piezoelectric transducer (-), Wu's modified current blocking circuit [3] (-), simplified current blocking circuit with parallel RL shunt branches (--) and simplified current blocking shunt circuit with series RL shunt branches (-·-).

CONCLUSION

This paper presented a simplified current blocking shunt circuit able to mitigate the vibratory amplitude of multiple resonance frequencies. This new arrangement results in a reduced number of electrical components compared to previous arrangements in the literature. Thanks to the proposed tuning methodology, a near-optimal design can be obtained with limited knowledge of the electromechanical system.

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