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Balanced Design of Resonant Shunted Piezoelectric Vibration Control

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ABSTRACT

Shunting of piezoelectric transducers and suitable electric circuits constitutes an effective passive approach to resonant vibration damping of structures. Most common design concepts for resonant RL shunt circuits rely on either maximization of the attainable modal damping or minimization of the frequency response amplitude, see [1, 2, 3]. However, the maximimum modal damping is sub-optimal near resonance, where it leads to constructive interference of two modes with identical frequency, while frequency response minimization leads to reduced implemented damping.

Assuming that the vibrations of the structure are dominated by a single mode, the equations of motion for the series RL electromechanical system can be written as, see e.g. [2],

$$\big(-\omega^2 + 2i\zeta_s\omega_s\omega + (1+\kappa^2)\,\omega_s^2 \big)\, x = \kappa^2\omega_s^2\xi + f \tag{1}$$

$$\big(-\omega^2 + 2i\zeta_e\omega_e\omega + \omega_e^2 \big)\, \xi = \omega_e^2\, x\,, \tag{2}$$

where x is the response amplitude, ξ is the normalized charge, ω_s is the natural frequency of the structure, ζ_s is the corresponding structural damping, κ is the generalized electromechanical coupling coefficient and ω_e and ζ_e are the frequency and damping ratio of the shunt circuit, respectively. For the parallel shunt circuit the right side of (2) is replaced by $(\omega_e^2 + 2i\zeta_e\omega_e\omega)x$.

The present paper proposes an explicit fully pole placement based design procedure for both series and parallel RL circuits. The procedure relies on equal modal damping and sufficient separation of the complex poles to avoid constructive interference of the two modes. It follows the procedure explained for the tuned mass damper in [4] and developed for a family of resonant control formats in [5]. It leads to the following expressions for the series circuit

$$\omega_e = (1+\kappa^2)\omega_s\,, \qquad \zeta_e = \sqrt{\frac{\kappa^2}{2(1+\kappa^2)}}\,, \tag{3}$$

while for the parallel circuit it gives

$$\omega_e = \omega_s\,, \qquad \zeta_e = \frac{\kappa}{\sqrt{2}}\,. \tag{4}$$

Figure 1 shows (a) the frequency response amplitude of the structure, (b) the frequency amplitude of the control, (c) the root locus trajectories and (d) the modal damping ratio. By comparison with existing design procedures it is demonstrated that the present calibration leads to a balanced compromise between large modal damping and effective response reduction with limited damping effort.

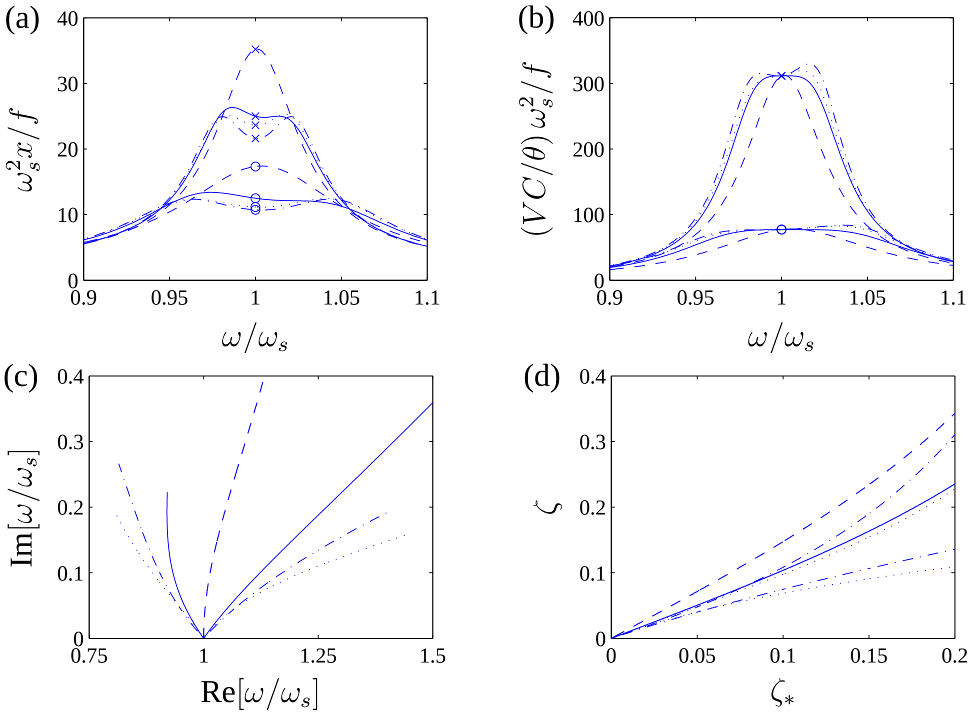

Figure 1: Series RL: (a) Response amplitude, (b) voltage amplitude, (c) root locus, (d) damping ratio. Balanced design (——), maximum damping (– – –), minimum amplitude (· · · · · ·), fixed point (– · – · –). Design damping ratio $\zeta_* = 0.02$ ($\times$) and 0.04 ($\circ$) in (a,b) and $\zeta_* = 0 \ldots 0.2$ in (c,d).

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