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MODIFYING RESONANCE MODES OF DISSIPATIVE STRUCTURES USING MAGNITUDES AND PHASE INFORMATION

Hugo J. Peters[1,2*], Paolo Tiso[1], Johannes F.L. Goosen[1] and Fred van Keulen[1]

[1] Structural Optimization and Mechanics, Delft University of Technology,
Mekelweg 2, 2628 CD Delft, The Netherlands
{h.j.peters-1, p.tiso, j.f.l.goosen, a.vankeulen }@tudelft.nl
[2] DevLab, Horsten 1, MMP 0.10, 5612 AX Eindhoven, The Netherlands

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Resonating structures are used in Flapping Wing Micro Air Vehicle (FWMAV) designs to increase energy efficiency [1]. The output amplitude of such a harmonically driven, non-proportionally damped structure is maximized if the driving frequency equals one of the structural resonance frequencies. This, and many other applications require a control approach to temporary modify the resonance mode.

Local structural changes are employed as a control approach to modify resonance modes of undamped structures [2]. That work uses the modal basis of the structure to increase intuitive insights while designing local structural changes to induce desired resonance mode modifications. However, a FWMAV is a strongly damped system. The resonance mode of non-proportionally damped structures is complex (non-synchronous), see Fig. 1a, which complicates the interpretation. This work presents a modal approach to control resonance mode modifications of damped structures in an insightful manner.

The desired mode modifications of damped structures might be twofold: (1) modify the relative amplitude at a specific point similar to the undamped situation or, (2) modify the phase difference between specific parts of the structure. For the control of a FWMAV this might mean: (1) modify the flapping amplitude of one of the wings or, (2) modify the phase between the flapping cycle of two different wings. Sensitivity analysis can be used to approximate resonance mode modifications due to local structural changes [3].

The sensitivity of resonance mode $\mathbf{x} \in \mathbb{R}^N$ to a structural change, s, can be expressed as,

$$(\mathbf{x})' = \left[\Re\left(\mathbf{x}\right)' + i\Im\left(\mathbf{x}\right)'\right], \tag{1}$$

where $(..)' = {}^{\partial\,(..)}/_{\partial s}$. In Eq. (1), $\Re\left(\mathbf{x}\right)'$ and $\Im\left(\mathbf{x}\right)'$ represent the real and imaginary part of

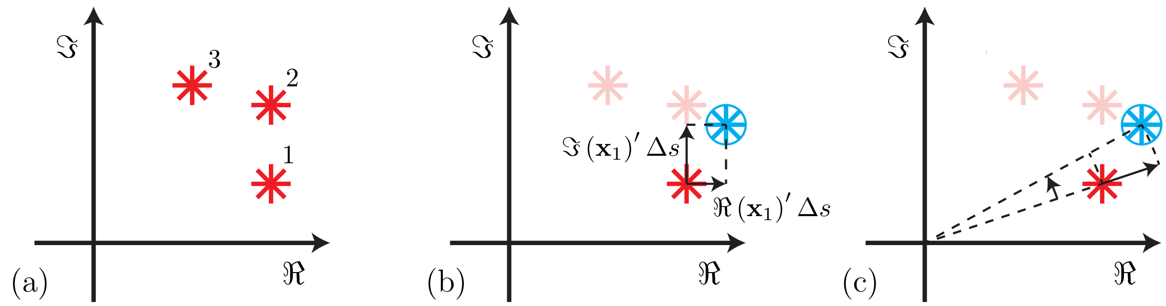

Figure 1: Illustrative sketch of the first eigenmode of a non-proportionally damped 3-dof system, visualized in the complex plane. (a) the non-synchronous nominal eigenmode, (b) change of dof 1 (i.e., towards encircled star) after a finite structural change, Δs_1, expressed in real and imaginary changes and, (c) change of dof 1 expressed in modulus and argument changes. The changes of dof 2 and 3 are not depicted for clarity reasons.

the resonance mode sensitivity, respectively. These sensitivities can be used to approximate mode modifications due to a finite structural change, Δs, see Fig. 1b. However, the interpretation is not straightforward since the modification leads to a relative shape and phase change between the dofs in the system. This work uses the modulus (magnitude) and argument (phase) changes of each dof, see Fig. 1c, to have a clear interpretation of the resonance mode modification in view of the desired modification.

We use a projection method to quantify the resonance mode (i.e., modulus and argument) modifications due to a specific structural change. This projection allows the determination of the locations at which a specific change scores maximum effect in terms of modifications. In this approach, it becomes clear whether or not a specific structural change introduces modifications to the relative modulus and the relative phase of the resonance mode.

The applied modal approach reduces the size of the problem which is attractive during analysis. By replacing the commonly used resonance mode sensitivities for modulus and argument sensitivities, the design of local structural changes to induce desired mode modifications becomes more intuitive. This work contributes to a better understanding of resonance mode modifications due to local structural changes for non-proportionally damped resonating structures.

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