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# SEMI-ACTIVE VIBRATION MITIGATION OF 2D FRAMES BY MEANS OF LOCAL NODAL RECONFIGURATION

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## 1. Introduction

A semi-active control strategy has been developed that aims at mitigating vibrations in 2D slender, planar frame structures. It is anchored in the energy management strategy called Prestress Accumulation–Release (PAR) [1].

Structural slenderness is often the result of high expectations for minimum weight of the designed structures. Such problems are frequently encountered in the case of structures designed to serve in space, where every additional kilogram put into orbit costs thousands of dollars. This undesirable feature raises a number of problems, one of which is the low effectiveness of natural mechanisms of vibration damping. In such a case, once excited, vibrations can result in repeated large deformations of the structure and last for a prolonged time, which may lead to fatigue damage and stabilization problems.

We have designed a vibration damping system to be used especially in such structures, however not exclusively. It consists of dedicated, especially designed, semi-active nodes that are used for dynamic reconfiguration of the controlled structure. These nodes can change their state of operation from frame node connection to a truss-like connection in a controlled manner. Transition between operating states is achieved by piezoelectric stacks which uncouple the interacting friction surfaces, thereby eliminating the ability of the node to transmit bending moments. Proper arrangement of such nodes in the system allows for a momentary change of its mechanical characteristics in order to significantly increase the dissipation rate and vibration mitigation effectiveness [2]. In particular, it is possible to extract individual beams from the frame structure and change their state of operation, leading to a temporary change in the effective stiffness of the entire structure. Such an approach enables the possibility to control a relatively complex frame structures that consist of many elements. It should be emphasized that the semi-active nodes are fail-safe: they remain in their default frame mode of operation when the source of the electric energy, which powers the control system, fails.

The proposed control strategy works in a closed-loop manner, where the feedback signal is the strain energy of the controlled structure. It can be either the energy of the entire structure or just one of its elements. This distinguishes between the so-called global and local versions of the control strategy. The PAR methodology is embodied here by accumulating the strain energy and releasing it by switching the state of semi-active nodes for a very short period of time. Such a switch results in the immediate change of kinematic constraints of the entire structure. Accumulated strain energy induces then high modes of vibration, where the energy is dissipated at a very high rate by means of standard material damping capabilities. This approach was derived heuristically, relying on the bang-bang control methodology. Switching moments from frame to truss states of operation of the semi-active nodes are determined as the local maxima of the feedback signal. Intuitively, such a condition ensures the highest possible potential of transferring the energy into high-frequency vibration modes.

The equation of motion of a structure equipped with *N* described semi-active nodes can be presented as:

$$\mathbf{M}\ddot{\mathbf{x}}(t) + (\mathbf{C} + \sum_{i=1}^{N} \gamma_i(t)\mathbf{C}_i)\dot{\mathbf{x}}(t) + \mathbf{K}\mathbf{x}(t) = \mathbf{f}(t) \tag{1}$$

where $\mathbf{M}$, $\mathbf{C}$ and $\mathbf{K}$ are global mass, damping and stiffness matrices, respectively, and $\mathbf{f}$ is the vector of possible external loading. The terms $\gamma_i(t)\mathbf{C}_i$ represent the coupling of rotational degrees of freedom (DOFs), which is modeled through a very high damping of the relative motion between the two selected DOFs. Here $\mathbf{C}_i$ is the matrix of the *i*th rotational damper, while $\gamma_i(t)$ is the corresponding damping coefficient that can be altered and serves as the control function that implements the derived control strategy.

In numerical simulations, parameters $\gamma_i(t)$ are changed in a bang-bang manner, based on the feedback signal:

$$\gamma_i(t) = \begin{cases} 0\,, & \text{at local maxima of } E_{\text{strain}} \\ \gamma^{\max}\,, & \text{otherwise} \end{cases} \tag{2}$$

In experimental work, the global strain energy has to be somehow approximated based on available sensor readings. Our approach employed laser measurements of in-plane displacements of the frame's free tip. We have chosen it as a good proxy for the strain energy changes associated with the eigenmodes which could possibly be controlled with our hardware. The local strain energy could be reliably measured using a set of strain gauges attached to the elements of interest. The length of the period in which the semi-active nodes remain in their truss-like state of operation can be determined in couple of ways. Numerically, the most effective condition seems to be based on the amount of the strain energy retained in the structure after the switch. However, a very simple time-based constraint is also sufficient and is preferable in experimental implementations.

## 2. Numerical and experimental results

The control strategy has been tested for an exemplary frame structure with two semi-active nodes shown in Fig. 1. Analyses were performed for the case of free and forced vibrations. Initial displacement conditions for the free vibration case were set correspondingly to the first and the second natural modes of vibration. In the case of forced vibrations we used harmonic and random force excitation. Exemplary results, presented in the form of time evolution of the normalized total mechanical energy (Fig. 1), demonstrate a very high effectiveness of the proposed strategy in mitigation of vibrations. For the first mode of vibration, the energy is dissipated almost completely after just two control switching cycles. For the second mode, the energy dissipation is less effective, however the control system enhances the natural dissipation abilities of the structure to a very large extent. Other results will be presented during the conference.

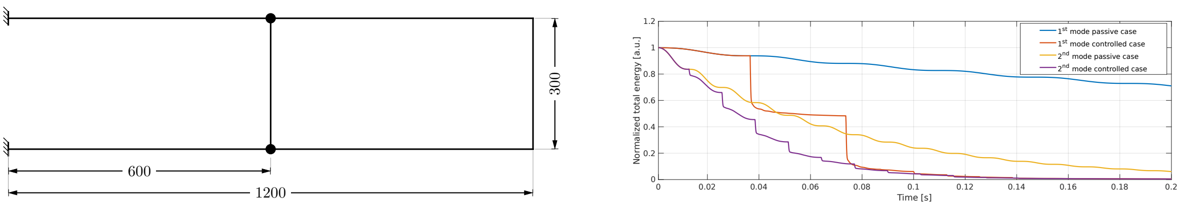


Figure 1: Exemplary frame structure (left) and the comparison of the total mechanical energy for the first and second natural modes of its free vibration (right)

## 3. Conclusions

The proposed vibration mitigation strategy has proven to be very effective in mitigating the vibrations of planar frame structures. Due to the difficulties in estimating the strain energy of the entire structure, its approximation must be used in experiments. Controlling the first few vibration modes could be successfully realized based on in-plane displacements of the frame free end or the related strain readings. This problem does not occur when the energy of individual elements is used.

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