UGO KCE VKXG'O KVI CVKQP 'QH'GZ VGTP CNN['KP F WEGF 'XKDT CVKQP U

B. Poplawski, G. Mikułowski, R. Wiszowaty, and Ł. Jankowski

Institute of Fundamental Technological Research, Polish Academy of Sciences, Warsaw, Poland

e-mail: bpop@ippt.pan.pl

1. Introduction

Almost all man-made structures are exposed to vibration. Regardless of whether these are large structures such as bridges or skyscrapers, machines with rotating parts such as engine shafts, frame structures or vehicle suspensions, excessive vibrations can be very harmful. From the perspective of their effects they can be seen as very spectacular (e.g., a collapse of a bridge) or not worth much attention (e.g., a failure of a motor shaft), but in each of these cases, the effect is the destruction of the structure and a negative impact on the users of these devices.

Several approaches can be used by the designers to overcome this phenomenon. The most basic, but often sufficient, method is to introduce changes in the mechanical parameters of the system affecting the severity of vibration in operational conditions, i.e., its mass or stiffness. If such design changes cannot be realized, or if vibration problems are detected after the system is manufactured, or if a vibration suppression system must be used for other reasons, one of the three basic types of such systems can be used [1].

The primary choice is usually a *passive vibration damping* system. These are relatively simple systems whose mode of operation is the passive dissipation of the energy of structural vibrations. Their design and simple functionality ensures that they are highly reliable, but their simplicity is reflected, unfortunately, in their limited efficiency. Their flexibility may be also considered as insufficient: once configured, even a small change in the specific operating conditions can result in a drastic loss of performance. This indicates a rather narrow spectrum (frequency range) of correct system operation.

Active systems constitute a much more effective damping approach. In this case, vibration attenuation is achieved not by means of dampers, but by actuators integrated into the structure. This approach allows to achieve very good results of vibration mitigation over a wide range of excitation frequencies. High efficiency, however, is burdened with a much higher degree of complexity of such a system as compared to the passive systems. In order to develop such a system, it is necessary to design the controller and install actuators that implement the control algorithm. During the vibration suppression, the actuators themselves require a large energy supply, which can be troublesome in some cases.

The compromise between these damping systems are *semi-active systems*, where the actuators are used to affect structural properties instead of exerting large external forces. In terms of reliability, semi-active systems can be compared with passive systems, while in terms of the efficiency of damping with active ones. They also do not require large amounts of electric energy to implement the control algorithm. Despite being a relatively new research area with less established design and development procedures, their advantages seem to be large enough to attract a growing number of scientists and engineers.

This contribution presents a strategy for semi-active reduction of forced vibrations in frame structures. Analogous damping technique proved to be effective in damping of free vibrations [2, 5]. The control strategy is based on the Prestress Accumulation–Release (PAR) concept and uses specially designed semi-active rotational nodes [4]. Successive decentralization of the damping system demonstrates that apart from the global mechanism of the energy dissipation based on the PAR, it is also possible to disperse it locally to individual beams that are separate elements of the damping system.

2. Control method

The equation of motion of the structure in which the proposed semi-active vibration damping system has been applied is as follows:

$$(1) \qquad \mathbf{M}\ddot{\mathbf{x}}(t) + \left(\mathbf{C} + \sum_i \gamma_i(t)\mathbf{C_i}\right)\dot{\mathbf{x}}(t) + \mathbf{K}\mathbf{x}(t) = \mathbf{f}(t)$$

where $\mathbf{M}$, $\mathbf{C}$ and $\mathbf{K}$ refer to the mass, damping and stiffness matrices, and $\gamma_i(t) \geq 0$ is the control function. The matrix $\mathbf{C_i}$ couples overlapping rotational degrees of freedom (Dofs) belonging to the ith node. It is used to effectively block the relative rotations of the involved rotational Dofs, which amounts to imposing a structural constraint in the form of $\dot{\theta}_1 = \dot{\theta}_2$. The vector $\mathbf{f}$ represents the excitation force, which is harmonic here.

Utilization of the Pontryagin minimum principle [3] with the control objective function formulated in the form of an integral of the global structural energy

$$(2) \qquad J = \frac{1}{2}\int_{T_s}^{T_f} \left(\dot{\mathbf{x}}^{\mathrm{T}}\mathbf{M}\dot{\mathbf{x}} + \mathbf{x}^{\mathrm{T}}\mathbf{K}\mathbf{x}\right)\mathrm{d}t$$

results in the optimal control strategy of a bang-bang type: the control function switches between $\gamma_i = 0$ and $\gamma_i = \gamma_i^{\mathrm{max}}$. The proposed decentralized control algorithm incorporates this approach, and the switching points are selected quasi-heuristically to correspond to the maxima of the local energy.

3. Numerical example

The investigated structure is a 2D frame with the dimensions shown in Figure 1. Two semi-active nodes are used to implement the control strategy.
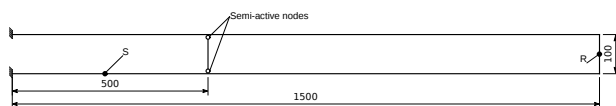

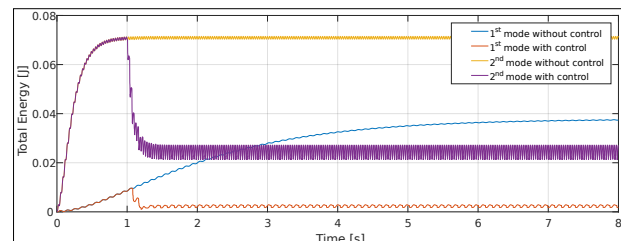Figure 1: Considered 2D frame model equipped with two semi-active nodes

Figure 2: Comparison of the total energy of the structure: controlled and uncontrolled case

Figure 2 shows the comparison of the total structural energy of the considered frame for the excitation applied in point R with the frequency of the first and the second eigenfrequencies of the structure. The results confirm the excellent efficiency of the proposed control algorithm in dissipating the structural energy. The energy reduction in the first vibration mode is more than ten times, while in the second mode it is almost threefold.

References

[1] B. Basu, O.S. Bursi *et al.* A European Association for the Control of Structures joint perspective. Recent studies in civil structural control across Europe. *Structural Control and Health Monitoring*, 21(12):1414–1436, 2014.

[2] B.Poplawski, G.Mikułowski, A.Mróz, and Ł.Jankowski. Decentralized semi-active damping of free structural vibrations by means of structural nodes with an on/off ability to transmit moments. *Mech Syst Sig Process*, 100, 2018.

[3] D.E. Kirk. Optimal Control Theory: An Introduction (republication). Dover Publications, 2004.

[4] A. Mroz, A. Orlowska, and J. Holnicki-Szulc. Semi-active damping of vibrations. Prestress Accumulation-Release strategy development. *Shock and Vibration*, 17(2):123–136, 2010.

[5] B. Poplawski, G. Mikułowski, A. Mróz, K. Sekuła, and Ł. Jankowski. A decentralized strategy of structural reconfiguration in mitigation of vibrations. In *Procedia Engineering*, volume 199, 2017.