

VMS Control of an Electronic Duffing Oscillator under an Impulsive Load

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Abstract. In this work, the Virtual Mechanical System (VMS) control law is applied to a host system with hardening spring in order to mitigate vibrations induced by an impulsive excitation. The goal is to actively control the vibrations in the host system caused by an impulse load. To this end, the VMS control law is applied. Using analytical techniques, insights into the capabilities of this control law is gained and a tuning strategy is proposed. Finally the results are experimentally verified using an electronic Duffing oscillator.

Introduction

The Virtual Mechanical System (VMS) control law [1] is an active vibration control law, which falls under the class of Passivity-Based Control (PBC) ensuring input-output stability. The control block scheme is shown in Fig. 1a. Note that the controller has its own dynamics. The controlled system can mathematically be viewed as two coupled systems, one host system and one virtual system (which is realised thanks to the choice of the control force). The VMS control law mimics the model of the host system and is coupled to it skew-symmetrically in the velocities, as in gyroscopic interconnections. Both the principle of similarity [2] and the gyroscopic coupling enable efficient energy exchange between the host system and the VMS (controller). The VMS control law aims to influence the energy flow within a system in two steps. First, the gyroscopic coupling and similarity principle are emplaced to redirect energy from the host system into the virtual system. Second, a damping strategy is designed and added to the virtual system to inhibit energy flow back to the host. The set of second-order equations of motion is investigated using the Complexification-Averaging (CxA) technique, which separates the dynamics into fast and slow flow dynamics. The study of the fixed points and bifurcation allows tuning of the gyroscopic coupling term n to achieve energy transfer. Once the energy is transferred to the VMS, it is inhibited of transferring back to the host system. To achieve this, a nonlinear damping term is designed and added to the VMS control law. The damping factor $C(x, \dot{x})$ is chosen as a function of the energy in the host system E_h : $C(x, \dot{x}) = \frac{C_{max}}{1 + e^{\frac{d(E_h(x, \dot{x}) - b)}{d}}}$. Finally, the results are applied to an experimental case study: the electronic Duffing oscillator [3]. This provides validation and insights into robustness of the controller.

Results and Discussion

The VMS control law was applied to an electronic Duffing oscillator, whose dynamics can be described by the equation of motion proposed previously (Fig. 1a). The uncontrolled impulse response is shown in the grey dotted line in Fig. 1b, while the controlled impulse response is shown in black. The uncontrolled 2%-settling time of x of the electronic Duffing oscillator for the chosen impulse load is 7.8267 s, while the VMS control law can reduce the 2%-settling time to 0.1745 s. This successful first experimental validation of the VMS control law not only confirms its theoretical foundations, but demonstrates its potential as a powerful tool for efficient vibration mitigation in real-world systems.

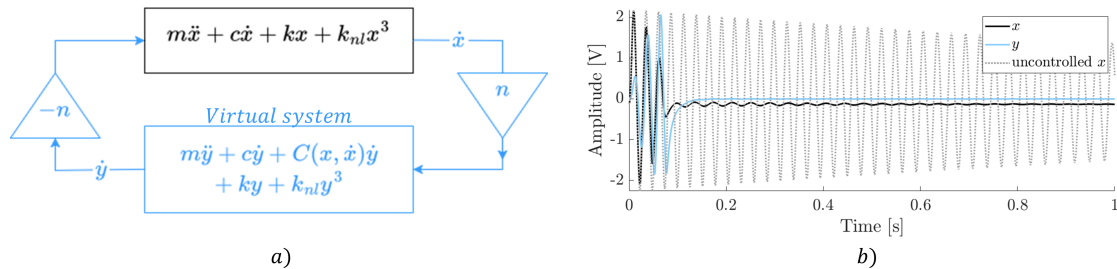


Figure 1: a) Schematic overview; b) Measured impulse responses of x of the controlled (black) and uncontrolled (grey) electronic Duffing oscillator and the virtual VMS state y (blue).

References

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