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Optimal-Based Structural Vibration Attenuation Using Nonlinear Tuned Vibration Absorbers

Authors : Pawel Martynowicz

Abstract : Vibrations are a crucial problem for slender structures such as towers, masts, chimneys, wind turbines, bridges, high buildings, etc., that is why most of them are equipped with vibration attenuation or fatigue reduction solutions. In this work, a slender structure (i.e., wind turbine tower-nacelle model) equipped with nonlinear, semiactive tuned vibration absorber(s) is analyzed. For this study purposes, magnetorheological (MR) dampers are used as semiactive actuators. Several optimal-based approaches to structural vibration attenuation are investigated against the standard 'ground-hook' law and passive tuned vibration absorber(s) implementations. The common approach to optimal control of nonlinear systems is offline computation of the optimal solution, however, so determined open loop control suffers from lack of robustness to uncertainties (e.g., unmodelled dynamics, perturbations of external forces or initial conditions), and thus perturbation control techniques are often used. However, proper linearization may be an issue for highly nonlinear systems with implicit relations between state, co-state, and control. The main contribution of the author is the development as well as numerical and experimental verification of the Pontriagin maximum-principle-based vibration control concepts that produce directly actuator control input (not the demanded force), thus force tracking algorithm that results in control inaccuracy is entirely omitted. These concepts, including one-step optimal control, quasi-optimal control, and optimal-based modified 'ground-hook' law, can be directly implemented in online and real-time feedback control for periodic (or semi-periodic) disturbances with invariant or time-varying parameters, as well as for non-periodic, transient or random disturbances, what is a limitation for some other known solutions. No offline calculation, excitations/disturbances assumption or vibration frequency determination is necessary, moreover, all of the nonlinear actuator (MR damper) force constraints, i.e., no active forces, lower and upper saturation limits, hysteresis-type dynamics, etc., are embedded in the control technique, thus the solution is optimal or suboptimal for the assumed actuator, respecting its limitations. Depending on the selected method variant, a moderate or decisive reduction in the computational load is possible compared to other methods of nonlinear optimal control, while assuring the quality and robustness of the vibration reduction system, as well as considering multi-pronged operational aspects, such as possible minimization of the amplitude of the deflection and acceleration of the vibrating structure, its potential and/or kinetic energy, required actuator force, control input (e.g. electric current in the MR damper coil) and/or stroke amplitude. The developed solutions are characterized by high vibration reduction efficiency – the obtained maximum values of the dynamic amplification factor are close to 2.0, while for the best of the passive systems, these values exceed 3.5.

Keywords : magnetorheological damper, nonlinear tuned vibration absorber, optimal control, real-time structural vibration attenuation, wind turbines
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