Online adaptive semi-active vibration damping of slender structures subject to moving loads

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ABSTRACT

The paper is concerned with the adaptive optimal semi-active control of the slender structures subject to a load traveling with the high velocity. The examples of slender structures loaded by a moving force include trains and rail trucks as well as road vehicles and bridges interactions. Due to interaction between the structure and the load the vibrations of the structure are generated. These vibrations may lead to the wear of the structure and/or the reduction or loss of its stability. The reduction of these undesired oscillations without an excessive investment in its construction is of primary interest among transport engineering community. Statically strengthened structures are characterized not only by a sufficiently higher load carrying capacity but also by a greater mass. The latter feature often hardly meets technological requirements.

Many active or semi-active control systems to reduce the vibrations of the structure loaded by a moving load have been proposed in literature. In general, most of the existing optimal adaptive controllers are based on complex iterative procedures that often do not guarantee convergence to a solution in the required time. The authors previous reports indicate that the switched optimal controls can be very efficient tool in reducing the vibration levels of the structure. On the other hand, these controls exhibit a high sensitivity to changes of the speed of the travelling load. Therefore in the present paper the authors propose and implement an adaptive closed-loop control policy, where the optimal switched semi-active damping is subject to real-time adaptation according to changes in the measured velocity of the moving load and the estimated state of the structure.

In the paper the optimal bilinear control problem for the slender structure subject to the moving load is formulated. The objective functional related to the total energy of the structure is introduced. This objective can be used to provide smooth passages of vehicles and reduce the material stresses of the carrying structures. The control function is chosen as a change of the damping of the structure's supports. The aim of the control problem is to find such a control function to minimize the objective function. The online adaptive controller is based on the solution of two optimal control problems depending on the speed of the moving load as a parameter. The first one is a bilinear optimal control problem for a given reference passage velocity. The necessary optimality condition as well as the structure of optimal switching times are formulated for this problem. For the assumed reference velocity, a set of optimal switching times will be computed offline by solving the corresponding two point boundary value problem. The second optimal control problem, intended for a sequential solution, is formulated for the actual measured velocity. To find a set of optimal switching times for this problem, a simple gradient-based iterative procedure is used based on the optimal solutions computed for the reference speed and a set of functions describing the sensitivity of the system dynamics to the measured velocity. Since the sensitivity functions can be computed offline, the solution to the second problem can be obtained in a very short time. It allows a frequent update of the optimal controls, something which is essential for fast passages. The performance of the proposed adaptive method is validated by means of numerical simulations. The dependence of the optimal semi-active damping strategy on a wide range of perturbations of the moving load velocity as well as an initial state are investigated and reported. The obtained numerical results indicate that in terms of the assumed objective functional, the proposed adaptive controller can outperform the reference optimal solutions by over 50%.