New materials for passive vibration control: Optimization of passive vibration isolators

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Recent progress in material processing and manufacturing has motivated increased interest of the scientific community in material optimization. Tailoring material properties to achieve the optimal response to a given solicitation provides an important input to the new materials development. Even if the new material cannot be readily produced, the results can be understood as future challenges for material processing. This contribution is focused on optimization of material parameters characterizing a one-dimensional passive vibration isolator.

It is assumed that a mass of a given value is connected through a passive isolator to a fixed support. The mass is excited by a time-dependent set of forces. The objective is to determine the isolator characteristics that provide the optimal dynamic performance of the system. Following practical engineering requirements, the reaction exerted by the support and the displacement exhibited by the mass are the decisive criteria for optimization. Therefore the cost functional involves the minimization of a weighted average of the maximum transient and steady state response amplitudes for a set of predefined dynamic loads. The optimal one-dimensional isolator mechanical characteristics can be thus specialized depending on the material model assumed. Methods of discrete material models are implemented.

Two approaches are presented. In the first one, the design space is composed of non-linear load-displacement curves of each spring contained in the discrete material model, while all dampers are linear viscous. Dynamic stability is assured by non-decreasing load-displacement curves. In the second approach, all springs and dampers are linear and tailoring is enabled by adjusting a negative stiffness component and an additional tuning mass. As proven by Lakes and co-workers, extreme material properties (i.e. exceeding properties of each constituent) in terms of stiffness as well as damping can be reached when at least one spring component of the discrete model exhibits negative stiffness. In this approach the dynamic stability must be verified by standard methods.

For the first approach, a computational tool in Matlab environment was developed. Several material models can be implemented. The complex stiffness approach is used to formulate the governing equations in an efficient way. Steady-state solution is obtained by an iterative process based on the shooting method. Extension of the shooting method to the complex space is presented and verified. Optimization is based on a generic probabilistic metaheuristic algorithm, simulated annealing. For the second approach, an analytical solution is presented in the complex space. Then the optimization is performed by parametric and sensitivity analyses.

The results obtained can facilitate the design of elastomeric materials with improved behaviour in terms of dynamic stiffness. Both approaches confirm the important role of quasi-zero stiffness and negative components in passive vibration control.

The conclusions of this study can have a direct and immediate impact on product design and development, especially in the design of new mechanical components such as engine mounts or new suspension systems.

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