Optimization of linear and non-linear one-dimensional visco-elastic isolators for passive vibration control

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Recent progress in material processing and manufacturing have motivated increased interest of the scientific community in material optimization. It is obvious that better solutions can be identified by material optimization combined with other optimization methods than for instance by strict shape optimization of a given material. Tailoring material properties to achieve the optimal response to a given solicitation provides an important input to the new materials development. Results are relevant not only in cases when the new material can be readily produced. Other results can be understood as future changes for material processing. This contribution is focused on to optimization of material parameters characterizing 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 which will provide an optimal dynamic performance of the system. Following engineering practical 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 by non-linear load-displacement curve 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 the stiffness as well as damping, is possible to reach 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 generic probabilistic metaheuristic algorithm, simulated annealing. For the second approach analytical solution is presented in 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 important role of quasi-zero stiffness and negative components in passive vibration control.

Conclusions drawn can have a direct and immediate impact on product design and development, especially in the design of new mechanical components such as engine mounts and /or new suspension systems.