Doctoral Dissertation
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Spatial damping identification and control of mechanical systems

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Abstract

This dissertation addresses two research questions: 1) spatially identify dissipations in mechanical systems and 2) actively control the dissipation spatial distribution. Dissipation is here intended as the transformation of mechanical energy in another form of energy, irrecoverably lost.

In structural dynamics dissipations are usually known as the effects of damping. The inverse problem of damping identification and modelling is still not completely solved in literature, with huge space for research, while inertial and elastic properties of mechanical systems are well understood.

The thesis focusses on direct spatial damping identification for enhanced damping layouts. A brief explanation of the keywords is required to fully understand the thesis aims: “Direct” means using straightway experimental measures of the system behaviour, acquired with standard techniques to make the procedure feasible in all the contexts; “Spatial” stands for damping matrices identification, to be distinguished from damping identification in terms of modal properties; “Damping Identification” focus the attention on the inverse problem of extrapolate the dissipations properties from real structures, in particular: to identify the most accurate damping model able to describe the dissipations in the system, to localise the dissipation sources within the structure and to quantify their dissipation levels; finally “Enhanced Damping Layouts” suggests improvements of the dissipation level and distribution, i.e. the damping layout, imposing the desired dynamic behaviour to the system, without changing its structural design.

The identification of the damping matrix is achieved by a novel damping matrices identification method, called Stabilised Layers Method. The presented method belongs to the receptances based methods, it can identify “physical” linear viscous and structural damping matrices of a mechanical system using standard experimental frequency response functions and the system geometry, which is usually known.

The Stabilised Layers Method identifies non-classical damping matrices, introducing non-proportional and localised damping sources. Non-classical damping matrices have the advantage of representing better the system behaviour than classical proportional damping, although it introduces a complication in the mathematical model.

The damping matrices identified using Stabilised Layers Method are the closest to the real dissipation distribution in the system, among the infinite energetically equivalent possible identification solutions.

The Stabilised Layers Method is also extended to the identification of systems with a localised amplitude dependent damping nonlinearity.

The design of systems vibrational behaviour and damping layout in different working condition is achieved applying real time active control on the already identified system. The system desired behaviour is assigned, without changing the structural design, using real time active control. Two different control strategies are experimentally implemented to assign the desired poles to the system. The control laws not only allow to change the damping distribution, but also to assign convenient natural frequencies to the system. The first control strategy is state space feedback linearisation, which requires an accurate identification of the system model. The other strategy is a receptances based version of the feedback linearisation, which allows to obtain the same results requiring only the experimental open loop response of the system.

The Stabilised Layers Method is validated against experimental applications. A simple three degrees of freedom test-rig is identified in several configurations, to assess the robustness of the method. The identified results are very close to the reference values. The Stabilised Layers Method is applied to the identification of damping distribution of an industrial body in white car chassis. The identified damping distribution is realistic, and the quantification of suspensions system damping is perfectly aligned with the reference values.

The extension to nonlinear damping identification is applied in the experimental identification of a nonlinear magnetic damping test-rig. The nonlinear damping force identification results agree with the literature knowledge.

The damping layout of the already identified three degrees of freedom system is experimentally modified using input-output feedback linearisation control. The desired dynamic behaviour is assigned to the system validating both the classical feedback linearisation applied to non-smooth nonlinear system and the receptances based feedback linearisation.