Modeling and experimental identification of vibrating structures: localized and distributed nonlinearities

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Summary

Nonlinearity is a frequent companion of engineering structures: it occurs anytime the outputs of a system cannot be expressed in terms of linear superposition of the inputs, a rare circumstance in the real world. Despite the long tradition of studies in nonlinear systems theory, the transposition of such knowledge to the structural engineering world is quite recent and has gained more importance in the very last decades, to address the ever-increasing demand of improved performances driven by industrial needs.

In this framework, nonlinear features often represent obstacles or unwanted effects that might compromise the behavior of the engineering structures, or even bring dangerous consequences. For this reason, it is important to be able to recognize and characterize them, both from modeling and experimental point of views. The latter case can be implemented via nonlinear system identification techniques, that allow the extraction of information about the dynamical behavior of a structure from the measured data. Fairly, this is just a part of the story, as a structure can be also designed to behave nonlinearly, to take advantage of some nonlinear effects that would not exist in the linear regime. This is for instance the case of negative stiffness absorbers, composites, nonlinear (meta)materials or slender elements.

This doctoral dissertation attempts to develop robust techniques for nonlinear vibrating structures, in order to give a contribution to the current unsolved challenges in the field, by identifying nonlinear features from real structures. Complex nonlinear dynamical phenomena are observed and modeled, considering both scaled-laboratory and real-life applications. In particular, the techniques presented in this thesis are based on the nonlinear subspace identification (NSI) method. NSI is meant to extract information about the nonlinear behavior of structures directly from the measured data, including the classical modal parameters (natural frequencies, damping ratios,

mode shapes), plus details about the nonlinearity itself. The method was originally designed to work with input-output data of systems with localized nonlinearities, but the extension to output-only free-decay measurements is presented, as well as to the case of distributed nonlinearities. The latter in particular has a wide range of applications, from wind turbines to aerospace vehicles.

The developed techniques are compared with the ones available in the literature, and numerical examples are very often proposed to assess the presented strategies. Eventually, the final application is related to the railway field and concerns the interaction between pantograph and catenary for high speed trains. The focus here is on improving the performances of the system by designing ad-hoc nonlinear damping elements. Therefore, the design process is presented, from the nonlinear modeling of the structure via a custom FE implementation, to the experimental testing and the nonlinear system identification with NSI.

Results show a high degree of confidence in the adopted methodologies and pave the way to the application of nonlinear tools such as NSI to the industrial world.