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Simulation and Experimental Methods for Characterization of Nonlinear Mechanical Systems

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Abstract

Trial and error and the use of highly time-consuming methods are often necessary for investigation and characterization of nonlinear systems. However, for the rather common case where a nonlinear system has linear relations between many of its degrees of freedom there are opportunities for more efficient approaches. The aim of this thesis is to develop and validate new efficient simulation and experimental methods for characterization of mechanical systems with localized nonlinearities. The purpose is to contribute to the development of analysis tools for such systems that are useful in early phases of the product innovation process for predicting product properties and functionality. Fundamental research is combined with industrial case studies related to metal cutting. Theoretical modeling, computer simulations and experimental testing are utilized in a coordinated approach to iteratively evaluate and improve the methods. The nonlinearities are modeled as external forces acting on the underlying linear system. In this way, much of the linear theories behind forced response simulations can be utilized. The linear parts of the system are described using digital filters and modal superposition, and the response of the system is recursively solved for together with the artificial external forces. The result is an efficient simulation method, which in conjunction with experimental tests, is used to validate the proposed characterization methods.

A major part of the thesis addresses a frequency domain characterization method based on broad-band excitation. This method uses the measured responses to create artificial nonlinear inputs to the parameter estimation model. Conventional multiple-input/multiple-output techniques are then used to separate the linear system from the nonlinear parameters. A specific result is a generalization of this frequency domain method, which allows for characterization of continuous systems with an arbitrary number of localized zero-memory nonlinearities in a structured way. The efficiency and robustness of this method is demonstrated by both simulations and experimental tests. A time domain simulation and characterization method intended for use on systems with hysteresis damping is also developed and its efficiency is demonstrated by the case of a dry-friction damper. Furthermore, a method for improved harmonic excitation of nonlinear systems using numerically optimized input signals is developed. Inverse filtering is utilized to remove unwanted dynamic effects in cutting force measurements, which increases the frequency range of the force dynamometer and significantly improves the experimental results compared to traditional methods. The new methods form a basis for efficient analysis and increased understanding of mechanical systems with localized nonlinearities, which in turn provides possibilities for more efficient product development as well as for continued research on analysis methods for nonlinear mechanical structures.

Keywords

nonlinear structural dynamics, simulation, system characterization, experimental methods.