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An efficient mode-based alternative to principal orthogonal modes in the order reduction of structural dynamic systems with grounded nonlinearities

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ABSTRACT

An alternative order reduction technique, based on the local equivalent linear stiffness method (LELSM), is suggested in this paper and compared with the principal orthogonal decomposition (POD) and the linear-based order reductions of structural dynamic systems with grounded cubic and dead-zone nonlinearities. It is shown that the updated LELSM modes approximate the principal orthogonal modes (POMs) of these systems with high accuracy especially at initial conditions corresponding to the linear modes of these systems. The use of the POMs for order reduction of nonlinear structural dynamic systems, while previously shown to be effective, requires that the solution response matrix in space and time should be obtained *a priori* while the alternative LELSM technique in this paper has no such requirement. The methods are applied to illustrative 2-dof (two degree-of-freedom) and 40-dof spring–mass systems with cubic and dead-zone nonlinearities. The reduced models of these systems in physical coordinates, obtained via updated LELSM modes, have been found nearly equivalent to POD modal-based reduced models and more accurate than the linear-based reduced models. Like POD modal-based order reduction, LELSM modal-based order reduction gives in-phase time histories with the exact numerical solution of the full model for long time periods of simulation. As a result, the updated LELSM modes are proposed as an alternative to POMs in order reduction of structural dynamic systems with grounded nonlinearities.

1. Introduction

The problem of characterizing the motion of a structural system with mass, damping, and stiffness matrices by a model which has lower dimension than the original model is considered. For such systems, it is often possible to compute the response of the system in terms of a subset of the original coordinates. For time-invariant systems, the task of order reduction of linear and nonlinear structural systems has received a considerable amount of attention [1–9]. In order to obtain accurate reduced models for nonlinear systems, the nonlinear normal modes (NNMs) are used to describe the motion as nonlinear functions of a subset of all the natural coordinates. The method is well known from its reformulation by Shaw and Pierre [10], in which the NNMs were defined as invariant manifolds in the phase space. Based on this concept, NNM-based reduced models were obtained in both state space and structural (second order) forms by approximating the invariant manifolds by polynomials. This technique has also been extended to time-periodic systems in which use is made of the Liapunov–Floquet transformation [11,12].

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