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Finite Element Computation of Nonlinear Normal Modes

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The dynamic systems theory is well-established for linear systems and can rely on mature tools such as the theories of linear operators and linear integral transforms. This in modal analysis, i.e., the computation of vibration modes, is really quite sophisticated and advanced. Even though linear modal analysis served, and is still serving, the structural dynamics community for applications ranging from bridges to satellites, it is commonly accepted that nonlinearity is a frequent occurrence in engineering structures.

Because linear modal analysis fails in the presence of nonlinear dynamical phenomena, the development of a practical nonlinear analog of modal analysis is the objective of this research. Realizing that most contributions in the literature for the computation of nonlinear normal modes (NNMs) rely on asymptotic techniques which are limited to weakly nonlinear regimes, this study targets the numerical computation of nonlinear normal modes defined as invariant manifolds in phase space [1]. Specifically, a new finite-element-based technique is proposed to solve the set of partial differential equations governing the manifold geometry. The algorithm is demonstrated using a two-degree-of-freedom system possessing cubic stiffness with

$$Y_2(u,v) = \frac{\partial X_2(u,v)}{\partial u}v + \frac{\partial X_2(u,v)}{\partial v}f_1(u,v,X_2,Y_2)\,, \tag{1}$$

$$f_2(u,v,X_2,Y_2) = \frac{\partial Y_2(u,v)}{\partial u}v + \frac{\partial Y_2(u,v)}{\partial v}f_1(u,v,X_2,Y_2)\,, \tag{2}$$

where $X_2(u,v)$ and $Y_2(u,v)$ are the unknown fields, and f_1 and f_2 the restoring forces at degrees of freedom 1 and 2, respectively. A comparison between two different finite element approaches is also performed.

References

[1] S. W. Shaw and C. Pierre. Normal modes for non-linear vibratory systems. *Journal of Sound and Vibration*, 164:85–124, 1993.