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Investigating nonlinearity in a bolted structure using force appropriation techniques

B. Pacini[1], D. Roettgen[1], D. Rohe[1]
[1] Sandia National Laboratories*

Abstract

Most mechanical and aerospace structures contain nonlinearities due to frictional contact at joints. Two methods to characterize these nonlinearities are Nonlinear Modal Models (NLMMs) and Nonlinear Normal Modes (NNMs). Typically, NLMMs assume that modal superposition is valid for in the amplitude range of interest and have been used to capture the amplitude dependent stiffness and damping in weakly nonlinear structures. NNMs do not rely on this modal superposition assumption and are used to characterize the changes in natural frequencies and mode shapes as response energy increases but rarely consider any nonlinear damping in the structure. They can also be used to observe interaction between modes. Previous works have shown that NNM solutions can be experimentally obtained by using force appropriation where, for a given excitation amplitude, the input frequency is changed until the force is 90 degrees out of phase with the acceleration. This work demonstrates the use of this force appropriation technique on a bolted structure comprising a cylinder, plate and beam with large continuous interfaces resulting in significant damping nonlinearities. The amplitude dependent frequency, dissipation and deflection shape of the structure will be assessed by exciting the structure at multiple force levels. Finally, these amplitude dependent parameters will be compared to those obtained using NLMM testing and analysis techniques.

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Techniques for Nonlinear Identification and Maximizing Modal Response

D. Roettgen[1], B. Pacini[1], R. Mayes[1]
[1] Sandia National Laboratories*

Abstract

Recent research has shown that weakly nonlinear structures can be represented with a nonlinear modal model. These models are traditional modal models where the linear spring and dampers associated with each mass are augmented with nonlinear elements. The nonlinear parameters are extracted from test data where the structure is excited to a high response level. While this approach is an effective method to capture the nonlinear characteristics of a structure, the model is only valid for the response amplitude range achieved during testing. Thus, there is a need to maximize the modal amplitude excited in these weakly nonlinear structures to increase the usable range of the nonlinear modal models. Previous works have compared hammer testing to windowed sinusoid shaker testing, the latter of which was shown to be a promising technique for increasing the modal amplitude. In this work the windowed sinusoid technique is further investigated to understand how window parameters (e.g. window width) can be optimized to maximize the modal amplitude. In addition, the windowed sinusoidal approach will be compared to other shaker excitation techniques.

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Influences of modal coupling on experimentally extracted nonlinear modal models

B. Moldenhauer[1], A. Singh[1], P. Thoenen[2], D. Roettgen[3], B. Pacini[3], R. Kuether[3], M. Allen[1]
[1] University of Wisconsin – Madison, Engineering Physics Department
[2] University of Southern California, Department of Mechanical Engineering
[3] Sandia National Laboratories*

Abstract
Research has shown that mechanical structures can be modeled as a combination of weakly nonlinear uncoupled modal models. These modal models can take many forms such as a basic cubic stiffness and damping forces, or a modal Iwan model. This method relies on two assumptions: 1) the mode shapes of the structure are not amplitude dependent, and 2) the modes of the structure do not couple or interact in the amplitude range of interest. Recently, a hypothesis was proposed that when multiple modes are excited that exercise the same nonlinear joint, the modes begin to couple. This hypothesis is tested on a physical system using a series of narrow-band and broad-band excitation techniques via a modal shaker. The resulting amplitude dependent stiffness and damping from the various excitation (or modeling?) methods will be compared to see if the simultaneous excitation of multiple modes changes the observed nonlinear characteristics of the structure.

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How linear is a linear system?

D. Roettgen[1], B. Pacini[1], B. Moldenhauer[2]
[1] Sandia National Laboratories*
[2] University of Wisconsin – Madison, Engineering Physics Department

Abstract
When experimentally determining the modal properties of a structure, linear behavior is typically assumed; the natural frequencies and damping in the structure are presumed to not change with response level. However, in many assembled structures, components are connected through bolted joints which result in nonlinear response due to frictional contact at these interfaces. Depending on the intended use of the data, this nonlinear response can result in unacceptable errors, as illustrated by the case study in this work. A linear substructuring problem is presented which demonstrates the propagation of slight damping errors in subcomponent models into the assembly model's response. This paper will conclude with some lessons learned and heuristics for capturing true linear parameters when testing a weakly nonlinear structure.

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