

Public Abstract

First Name:Jiazhu

Middle Name:

Last Name:Hu

Adviser's First Name:Perjin

Adviser's Last Name:Pai

Co-Adviser's First Name:

Co-Adviser's Last Name:

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Title:Nonlinear Mechanics and Testing of Highly Flexible One-Dimensional Structures Using a Camera-Based Motion Analysis System

Recent developments in aerospace exploration have stimulated extensive research interest in Highly Flexible Structures (HFSs), such as dish antennas, space telescopes, and solar collectors due to their prospectively wide applications and involved challenging mechanics problems. As the basic structural elements for these HFSs, strings, cables and beams play an important role in the high precision design of these structures. Large elastic deformation and nonlinear dynamics of these one-dimensional structures need to be fully understood in order to design such structures and to control them when they are in service. In this dissertation, exact equations of motion for finite-amplitude vibration of strings were derived based on a fully nonlinear string model. The Method of Multiple Scales (MMS) was used to solve the weakly nonlinear governing differential equations of strings subjected to a harmonic base-excitation. Two different ways of using the MMS were followed and the results were compared. Bifurcations of solutions due to variations of system parameters (e.g., the frequency detuning, excitation amplitude and damping coefficient) were studied in detail using the obtained modulation equations in both polar and Cartesian forms. Frequency response curves, trajectories of various orbits, frequency spectrum, bifurcation structures, and bifurcation diagrams were used for a detailed qualitative as well as quantitative analysis of dynamic responses. A 3D motion analysis system was used to perform dynamic testing on string and cable vibrations. Strings with different tensions and cables with different sag to span ratios were tested and the results were comparatively analyzed. A modal decomposition method based on the use of the first four linear mode shapes was used to extract time- and space-varying modal coordinates to reveal modal coupling caused by internal resonance and other nonlinear phenomena. Experimental frequency response curves of physical points on a string were obtained and compared with the theoretical ones. For cables, experimental frequency response curves of modal coordinates were used for analysis. Frequency spectra of responses of one marker and four modal coordinates, phase relations between participating modes, and Poincare sections were used to characterize vibrations. Linear and nonlinear modal couplings, resulting in isolated and simultaneous internal resonances were observed in cable vibration at the first crossover point. The concept of nonlinear normal mode was questioned.

To understand the packaging of 1-D structures, we also performed large-deformation analysis of a triangular frame using a geometrically exact beam theory that accounts for large displacements, large rotations, initial curvatures, extensionality, and transverse shear strains. The problem was presented as a boundary value problem described by a set of first-order ordinary differential equations. The multiple-shooting method was used to solve this two-point boundary value problem. Numerically exact deformed geometries at different stages of packaging were obtained. Appropriate loading schemes and corresponding efficient and controllable deployment schemes were also discussed.