INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI
SHORT ABSTRACT OF THESIS

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SHORT ABSTRACT

Abstract

This dissertation deals with the nonlinear dynamics and active/passive control of parametrically excited beam-like slender structures using piezoelectric actuators, viscoelastic damping materials and functionally graded materials (FGMs). First, the dynamics of smart slender beams is studied where the main focus is to investigate the usefulness of shear mode and extensional mode piezoelectric actuators in active control of complex nonlinear dynamics of the smart beams in pre- and post-buckled states. The subsequent study is carried out to investigate the usefulness of viscoelastic damping materials in passive control of complex dynamics of parametrically excited beams. However, for the corresponding dynamic analysis, a formulation of the HBM-based full-order FE model (FOM) is derived by introducing three new strategies, namely (a) a special factorization of the nonlinear strain-displacement matrix, (b) exploitation of orthogonality of Fourier basis functions and (c) reduction of various viscoelastic constitutive relations into a generalized mathematical form for the time-periodic stress/strain. Further, to achieve reduced computational time in evaluating nonlinear transient/frequency responses, the nonlinear FOMs are subsequently reduced to reduced-order FE models (ROMs). The formulation of nonlinear ROMs is carried out at the elemental level without involving the full-order system matrices/vectors, where the primary contribution lies in the formulation of the nonlinear memory-load vector. Besides the reduced computational time, the accuracy of the nonlinear ROMs is achieved by proposing a new methodology for computation of appropriate reduced basis vectors (RBVs) using normal vibration modes (NMs), static modal derivatives (MDs) and proper orthogonal decomposition (POD) method. Finally, an FGM is taken as the material of a beam-like slender structure, where the main focus is to investigate the influence of graded material properties of the slender FGM structure on its nonlinear dynamic characteristics under the parametric excitation. This study is performed considering a pinned-pinned vertical/inclined FG pipe conveying hot fluid with the steady/pulsatile flow velocity.

This dissertation deals with the nonlinear dynamics and active/passive control of parametrically excited beam-like slender structures using piezoelectric actuators, viscoelastic damping materials and functionally graded materials (FGMs). First, the dynamics of smart slender beams is studied where the main focus is to investigate the usefulness of shear mode and extensional mode piezoelectric actuators in active control of complex nonlinear dynamics of the smart beams. Two smart beams are considered for separate use of the two different kinds of piezoelectric actuators; however, these beams are considered to operate under the transverse or axial compressive harmonic load while the actuators are activated by supplying the external electric field according to the velocity feedback control law. The dynamics of the smart beams is analysed by deriving the geometrically nonlinear electro-elastic incremental equations of motion in the finite element (FE) framework. The FE equations of motion are solved using Bathe time-integration method for evaluation of the transient responses, while the frequency responses are evaluated by implementing the harmonic balance method (HBM) in conjunction with a numerical continuation technique. The results for the transverse harmonic load reveal that both the actuators are capable of attenuating the large amplitude vibration of the smart beams; however, the application of the shear/extensional mode actuator is mainly limited to a certain extent of the load-amplitude. Under the axial compressive harmonic load, the dynamics of the smart beams in the pre-buckled state appears through the parametric instabilities. However, once the buckling occurs, the smart beams exhibit complex nonlinear dynamics due to the appearance of the snap-through periodic motion and the chaotic motion through the symmetry breaking, period-doubling/demultiplying and saddle-node bifurcations. The presented results mainly reveal the suitability of the shear mode and extensional mode piezoelectric actuators in active control of such dynamic instabilities and the associated complex motion of the smart beams.

The subsequent study is carried out to investigate the usefulness of viscoelastic damping materials in passive control of complex dynamics of parametrically excited beams. The viscoelastic damping materials are used through the constrained-layer damping (CLD) arrangement and modelled using fractional Zener constitutive relation. The corresponding dynamic analysis is carried out by deriving full-order nonlinear FE models (FOMs) of CLD treated beams in the time and frequency domains, where the HBM is employed for the derivation of frequency-domain FOM. However, to achieve reduced computational time in evaluating nonlinear transient/frequency responses, the nonlinear FOMs are subsequently reduced to reduced-order FE models (ROMs).

The nonlinear FOM in the time-domain is derived following the conventional formulation methodologies. However, the derivation of the nonlinear FOM in the frequency domain using HBM involves a tedious formulation mainly because of (a) an arbitrary number of harmonic terms in HBM and (b) the involvement of temporal derivative of stress/strain in the viscoelastic constitutive relation. Presently, this formulation of the HBM-based FOM is eased somewhat by introducing three new strategies, namely (a) a special factorization of the nonlinear strain-displacement matrix, (b) exploitation of orthogonality of Fourier basis functions and (c) reduction of various viscoelastic constitutive relations into a generalized mathematical form for the time-periodic stress/strain. The subsequent formulation of nonlinear ROMs is carried out at the elemental level without involving the full-order system matrices/vectors, where the primary contribution lies in the formulation of the nonlinear memory-load vector. It is observed that the present formulation of nonlinear ROMs at the elemental level yields a significant reduction of the computational time in the evaluation of nonlinear responses of CLD treated beams. Besides the reduced computational time, the accuracy of the nonlinear ROMs is achieved by proposing a new methodology for computation of appropriate reduced basis vectors (RBVs) using normal vibration modes (NMs), static modal derivatives (MDs) and proper orthogonal decomposition (POD) method. It is observed that the present RBVs are robust ones in providing sufficient accuracy of the nonlinear ROMs, especially for accurate theoretical estimation of complex motion and dynamic bifurcations of CLD treated beams under the parametric excitation.

Using these ROMs, the usefulness of CLD treatment in passive control of complex nonlinear dynamics of parametrically excited beams is investigated, where the CLD treatment is configured in three different viscoelastic layered beams, namely (a) PCLD treated beam, (b) three-layered viscoelastic beam and (c) five-layered viscoelastic beam. The corresponding dynamic analysis reveals very complex motion of these viscoelastic layered beams involving various dynamic instabilities and chaotic oscillations. Besides, these beams also undergo the large-amplitude vibration through the snap-through periodic oscillation with respect to the zero equilibrium state. The CLD treatment is capable of attenuating this complex dynamics as well as large-amplitude vibration through the three/five-layered configuration. However, the PCLD configuration is not a suitable one for controlling this complex dynamics although it possesses greater static stability in comparison to the other two layered beams.