The Dynamical Response of Nonlinear Engineering Systems

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Almost every engineering system exhibits behavior which is nonlinear. For many systems the influence of these nonlinearities is minimal—a linear model is able to satisfactorily describe the dynamical behavior. However, as the influence of these nonlinearities grows, the resulting behavior of the system begins to diverge, sometimes dramatically, from the predictions of the linearized model. Such differences frequently arise as the forcing on the system increases or under specific forcing conditions such as occur at resonance. Moreover, there are certain types of dynamical behavior which can only be predicted by nonlinear systems. My research interests are focused on the investigation of the dynamical response of nonlinear engineering systems. My work has spanned across the areas of vibrations and dynamical systems, to contact dynamics and control theory, and an underlying theme to my research is the understanding of these systems through the development and analysis of simplified models.

Resonant Interactions in Dynamical Systems. [National Science Foundation; CMS–0084162, CMS–0201347]

Resonances in dynamical systems provide a mechanism through which complex coupled systems can exhibit unexpected dynamical behavior. The coupling, which is assumed to have only a small effect of the dynamical behavior of the individual components, is enhanced by the presence of the resonance so that the behavior of the overall system cannot be described by simply considering the individual components. The primary objective of this work is to determine how, near a state of resonance, the characteristics and properties of the components of the system, including the coupling between components, affect the response of the overall system. These phenomena are undesirable because the resonant behavior is often accompanied by vibrational amplitudes which grow in time, even if the system is near a state of resonance for only a short period of time. Such large amplitude vibrations can expedite failure due to fatigue or, in extreme cases, lead directly to failure. Using singular perturbation methods such as averaging, we restrict our analysis of the dynamics to the neighborhood of the resonance manifold, defined as a submanifold in phase space on which the resonance occurs. However, these reduced equations are nonetheless complicated, often possessing strong nonlinearities and a multi-dimensional phase space. Tools and techniques from applied dynamical systems are then used to analyze these reduced equations. The analytical predictions are then compared against the behavior of experimental systems.

Differential Models of Collisions. [National Science Foundation; CMS–0100137]

Impact describes the interaction between two or more bodies, and is an important feature in a wide variety of mechanical systems. However, a continuum description of the contact mechanics which describes this interaction is too complex and computationally intensive to be applied in situations with a multitude of contacts (e.g. granular flow, machine-tool vibrations) or in which the collision is a component of a larger simulation (e.g. robotic manipulators, vibroimpact systems). Instead, the impact is described by a simplified collision model which attempts to predict the post-collisional velocity of the body, given the the pre-collisional mass distribution and the pre-collisional velocity of the body. In general rigid body collision models, the post-collision state depends not only on the pre-collision velocities and material parameters, but the geometry of the collision as well. We are developing differential models of rigid body collisions with friction which allow for a separation of the geometric and material parameters which influence the outcome of the impact. The impactive event is modeled by a nonlinear system of ordinary differential equations which predicts the impulsive forces generated in the collision. The results can be checked against basic mechanistic considerations such as energy loss, and can be compared against more familiar algebraic models of restitution as well as finite element models based on continuum contact mechanics.

Health Monitoring of Rotordynamic Systems. [National Science Foundation; CMS–0219701]

Well-established procedures exist to monitor and diagnosis fairly severe problems with rotating machinery but little progress has been made in developing techniques to detect subtle changes in machine condition for both improved diagnostics, and to develop prognostic procedures for determining remaining service life. The proposed project uses a novel application of Active Magnetic Bearings (AMBs) as actuators for applying a variety of known force inputs to a spinning rotor in order to monitor and evaluate response signals resulting from these inputs on-line. Similar to modal analysis and other nondestructive evaluation (NDE) techniques which apply input signals to static structures in order to monitor responses, this approach will allow for the measurement of both input and output response in a rotating system for evaluation. However, unlike these techniques, the proposed procedure allows for multiple forms of force input signals to be applied to a rotating structure. The ability to examine a variety of both input and output information on-line will result in unprecedented levels of dynamic information facilitating new dramatically improved techniques for diagnosing subtle changes in machinery health and the development of accurate prognosis models.

Dissipation Induced by Mechanical Interfaces. [Sandia National Labs; 193122]

As the cost of computational resources decreases, the use of large scale modeling and simulation is increasingly being used to augment, and even replace full-scale experimental testing of complex engineering structures. However, to faithfully capture the dynamical behavior of these systems, models which accurately reflect the physics of the system under consideration must be developed. Specifically, these models must reflect a wide variety of mechanical phenomena over a wide range of length scales. Unfortunately, the ability to resolve all the length scales of complex structural systems remains outside the predicted computational resources for the next ten years. Thus, there is still a need to develop reduced order models which describe the dynamical behavior (elasticity, damping, etc.) of the components at the smallest length scales. Often, these smallest length scales are associated with the connections and interfaces between structural components, and these interfaces have been shown to play a significant role in the overall dissipation of structural systems. Because computational resources are indeed limited, the reduction of these fundamental models is of increasing interest to those who simulate large-scale structural systems. Current models to represent interfacial damping often require experimental trials which are valid only for specific structural systems and at loading levels near the calibration tests. The goal of this work is to identify model forms and parameters which relate to the fundamental physics of the connection and can be identified independent of the structural system in which the joint exists.

Modeling, Simulation, and Analysis of Bending Nanotubes. [National Science Foundation; DMS–0407361]

Carbon nanotubes possess unique structural, chemical, and electrical properties and hence offer great potential for use in future materials, sensors, and microelectronic devices. Despite these opportunities, few mathematical models can predict the mechanical behavior of such components, in particular multi-walled nanotubes, and hence the ability to design and engineer components that incorporate these novel structures is limited. The present research combines continuum mechanical modeling with molecular dynamics simulations to develop a multiscale description of the deformation of multiwall nanotubes. Within the framework of nonlinear shell theory, the influence of the van der Walls interactions between concentric layers is incorporated to study the mechanical phenomena unique to multiwall structures, such as wrinkling.

Other Current Research Topics

In addition to the above research areas, I am currently or have been involved in several other projects. In collaboration with faculty in the Division of Applied Mathematics, one such project seeks to model the fluctuations of atomic force microscopes subject to thermal excitations. Using a simple mathematical system to describe the AFM oscillations, we are able to characterize the structure of the excitation. Also, in collaboration with other faculty in engineering, the response of rotordynamic shafts within fluid bearings is under investigation to characterize the influence of the bearing surface properties on the shaft stability. Finally, the dynamics of deformable mirrors actuated with micro-electro-mechanical devices is under study.

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Biography

D. Dane Quinn was awarded the B.M.E. degree from Georgia Tech in 1991 and, in 1995, a Ph.D. from Cornell University in the Department of Theoretical and Applied Mechanics. He is currently an Associate Professor on the faculty of the University of Akron in the Department of Mechanical Engineering, and holds a joint appointment in the Applied Mathematics Division.

His research interests lie in the area of applied dynamical systems and mechanics. Specifically, he has considered the effects of resonances in nonlinear systems with applications to rotordynamics, spacecraft dynamics, and the mechanisms by which energy is transferred through mechanical systems. Since joining the University of Akron, he has initiated studies of differential collision models and research into structural health monitoring. Each of these projects is currently supported by the National Science Foundation. He is currently collaborating with researchers at Sandia National Laboratories modeling the dynamic response and structural dissipation induced by mechanical interfaces such as lap joints and bolted connections. In addition, he has worked in several related areas, including the modeling, simulation, and control of thermo-acoustic instabilities in aeropropulsion systems, celestial mechanics, nonlinear thermoelastodynamics, nonlinear control systems, and the evolution of virulence in age-dependent populations.

He has published numerous papers in archival journals and has presented his work at national and international scientific meetings. His research has led to over $500,000 in research funding. Finally, he is currently an Associate Editor of the Journal of Vibration and Acoustics and in 2005 was selected as the recipient of the Tau Beta Pi Outstanding Teacher Award for the College of Engineering. He currently lives in Akron, Ohio with his wife Kristen, children Kaelyn, James, and Ian, and his dog Madison.