MONOGRAPHS

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Nonlinear Dynamics of Continuous Elastic Systems

(with V.A. Krysko and A.F. Vakakis)
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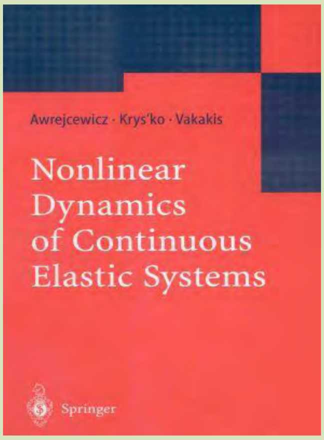
SUMMARY



Preface & Contents

Book Review

There are many monographs in the existing literature devoted to the static and dynamic behavior of plates and shells. Plates and shells are encountered often in engineering applications being integral parts of a wide range of constructions, such as machines, vehicles, airplanes, rockets, ships, bridges, buildings, and containers, to name a few. In addition to the usual requirements posed by engineers related to lightweightness, sufficient rigidity or flexibility, and robust stability properties, there is an additional class of a priori dynamical properties required by modern engineering applications where non-homogeneity and non-uniformity of structural components is often the norm in certain applications. In addition, strict operational requirements in modern engineering applications towards higher speeds, lighter construction, robust and reliable performance, dictates smaller margins of error or deviations from prescribed performances in adverse or uncertain forcing environments. This, in turn, requires the development of new analytical and computational tools capable of addressing challenging and not very well developed topics, such as, nonlinearities affecting the system performance, the effects of unmodeled dynamics on the stability of operation, and the role of uncertainties in the system parameters on the structural response. As a result, there is an ongoing effort to address such issues, leading to the development of new analytical and computational tools, some of which are discussed in this monograph.

The monograph follows an approach based on an integrated treatment of analysis and computation. Such a hybrid approach, coupled with computer algebra, can lead to results that cannot be obtained by other standard theories in the field. We show, that in a wide class of problems only a carefully prepared numerical experiment followed by purely mathematical considerations can finally lead to the sought results. The numerous analytical constructions are illustrated by examples of application and computational results. The figures, mathematical derivations and described algorithms are balanced so to attract potential readers, even those without a rigorous mathematical background.

Certain of the topics presented in this work can be considered as novel for a monograph on continuous elastic structures of this type. These include techniques and bibliography from the Russian literature not available until now in the Western Scientific and Technical Community; one of the first expositions in a monograph of the Proper Orthogonal (or Karhunen-Loeve) Decomposition (POD) methodology as applied to the dynamics of elastic continuous structures; application of a new technique based on non-smooth transformations to the analytic/numerical study of discretely supported or forced continuous systems; and certain techniques dealing with clearance and vibro-impact localization phenomena in coupled continuous

oscillators. Many of these results were published dispersedly in the archival literature during the last five years, and, as a result, have not attracted yet the attention of the vast part of the engineering community.

Chapter 1 of the monograph is devoted to the analysis of plates and shells with added elements (discrete additives). First a literature and research review is given implying the necessity of developing more accurate techniques for studying the dynamics of plates and shells in the framework of both non-classical and three dimensional (3D) elasticity theories. Special emphasis is given to the analysis of the full stress-strain distribution along the thickness of the plate (which is three dimensional in the neighborhoods of the joints between the continuous system and the discrete added masses). Furthermore, the obtained results within the context of 3D-theory provide the limits of validity of classical lower dimensional theories. Numerical algorithms together with numerical applications are included.

Chapter 2 deals with the so-called rational design of plates and shells. After a brief introduction, frequency spectra properties of orthotropic shells with varying thickness are described. In addition, the finite dimensional approximation of the problem of free vibration of a Timoshenko-like shell is discussed. Special attention is paid to two different methods of numerical analysis of plates and shells with variable thickness, namely the method of Bubnov-Galerkin (BG), and the method of variational iterations (MVI). These methods are widely recognized as being the most effective for solving various statics and dynamics problems in, the theory of plates and shells. The main problem of the BG method for dynamic problems relates to the lack of a relatively simple estimate for the errors involved in the discrete approximation, and to the lack of a strict mathematical formulation for the proper choice of basis functions. Both aspects are addressed in this monograph. Then, the issue of mass optimization of plates and shells with free vibration frequency constraints is formulated and rigorously discussed. Finite dimensional approximate techniques solutions for solving the optimization problem are outlined and numerically implemented. In addition, the optimization of the surfaces of plates and shells with constraints related to the distribution of their spectral lines is considered, together with optimization studies related to vibration isolation of plates subject to applied harmonic loads.

In the following three Chapters we present some new techniques for order reduction, vibro-impact analysis and discrete effects estimation of elastic structures. In Chapter 3 we introduce the method of proper orthogonal decomposition (POD). Whereas this method has been successfully applied in the past to many engineering fields including, fluid mechanics, acoustics, and optics engineering, its applications to structural dynamics are rather limited and very recent. This method provides an optimal orthogonal base in functional space for decomposing the dynamics of discrete or continuous oscillators. The POD modes (e.g., the elements of the basis) are axes of inertia of the 'cloud' of data in time and space that is obtained by measuring time-series of the structural response at different 'sensors' along the structure. We show that by using POD analysis one is able to produce low order models of structures with high modal densities and local nonlinearities, where traditional modal analysis or system identification methods cannot be applied. The method is applied to the analysis of the dynamics of a light weight truss and of systems with clearance nonlinearities. A special characteristic of the method is that it can be applied to linear as well as nonlinear problems, thus eliminating a drawback of many of the existing inverse techniques that are based on the assumption of linearity.

In Chapter 4 we provide some special mathematical techniques for analyzing discreteness effects in the dynamics of elastic structures. We introduce a non-smooth transformation of variables that permits the complete (exact) analytical elimination of singularities from the equations of periodically discretely supported or discretely forced continuous structures. Examples of application of this technique are given with the study of the static buckling of a discretely forced ring, and of the dynamics of a free or forced string resting on a discrete elastic foundation. This non-smooth technique paves the way for the analytic treatment of linear and nonlinear problems with singularities in their equations of motion due to forcing or boundary conditions. Indeed, we are unaware of any other existing analytical technique that can account exactly for nonlinear effects in elastic structures arising due to spatially periodic boundary supports.

In Chapter 5 we examine the dynamics of continuous systems with backlash nonlinearities, with motion-limiting constraints that introduce vibro-impact nonlinearities in the response, and with essential local nonlinearities. These types of nonlinearities are rather common in engineering applications. Due to the discontinuous nature of the backlash and vibro-impact nonlinearities, the associated dynamic analysis is quite challenging. We show that backlash and vibro-impact nonlinearities can be used to induce localization and motion confinement properties in symmetric, spatially extended structures, such as trusses. In other applications, we demonstrate that even small clearances can introduce highly unstable and sudden dynamic phenomena that, if unaccounted for, can result in early and sudden failure of the structures. Hence, the examples provided demonstrate clearly the beneficial or destructive influence that clearance or vibro-impact nonlinearities can have on the dynamics of continuous systems, and urge for careful consideration of the dynamic effects of this type of nonlinearities in practical structures.