Solid Mechanics and Its Applications

Volume 202

Series Editor

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Aims and Scope of the Series

The fundamental questions arising in mechanics are: *Why? How?* and *How much?* The aim of this series is to provide lucid accounts written by authoritative researchers giving vision and insight in answering these questions on the subject of mechanics as it relates to solids.

The scope of the series covers the entire spectrum of solid mechanics. Thus it includes the foundation of mechanics; variational formulations; computational mechanics; statics, kinematics and dynamics of rigid and elastic bodies: vibrations of solids and structures; dynamical systems and chaos; the theories of elasticity, plasticity and viscoelasticity; composite materials; rods, beams, shells and membranes; structural control and stability; soils, rocks and geomechanics; fracture; tribology; experimental mechanics; biomechanics and machine design.

The median level of presentation is the first year graduate student. Some texts are monographs defining the current state of the field; others are accessible to final year undergraduates; but essentially the emphasis is on readability and clarity.

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Dynamics and Vibrations

Progress in Nonlinear Analysis

Springer

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Preface

Introduction

Dynamical and vibratory systems are basically applications of mathematics and science to the solution of real-world problems. In the majority of real-life and applied phenomena in engineering sciences, as well as in a multiplicity of other sciences, solutions of specifically defined problems are the ultimate goal. In order to apply engineering or any other science, it is necessary to fully understand dynamical and vibratory systems and how to solve cases of either linear or nonlinear equations using analytical and numerical methods. It is of particular importance to study nonlinearity in dynamics and vibration, because almost all applied processes act nonlinearly. In addition, nonlinear analysis of complex systems is one of the most important and complicated tasks, especially in engineering and applied science problems.

There are only a handful of books that focus on nonlinear dynamics and vibrations analysis. Some of these books are written at a fundamental level that may not meet ambitious engineering program requirements. Others are specialized in certain fields of oscillatory systems, including modeling and simulation. In this book, we attempt to strike a balance between theory and practice, fundamentals and advanced subjects, and generality and specialization.

None of the books in this area have completely studied and analyzed nonlinear equations in dynamical and vibratory systems using the latest analytical and numerical methods, which, if included, would allow the user to solve problems without needing to study many different references. Therefore, in this book, we have chosen to use the latest analytic and numerical laboratory methods, referring to a bibliography of more than 300 books, papers, and research reports, many of them written by the authors of this book, and to consider almost all possible processes and physical configurations, thereby exploring new theories that have been proposed to solve real-life problems in engineering and applied sciences. In this way, the users (bachelor's, master's, and Ph.D. students, university teachers, and even workers in research centers in different fields of mechanical, civil, aerospace, electrical, chemical, applied mathematics, physics, etc.) can approach such systems with confidence. In the different chapters of the book, not only are linear and nonlinear problems, especially those in an oscillatory form, broadly discussed, but also applied examples are solved in a practical manner by the proposed methodology.

An abundant number of examples and homework problems are provided.

The users of this collection can achieve very strong capabilities in the area, especially of nonlinear phenomena in dynamically and vibratory systems, such as the following:

- A complete understanding of the nonlinearity sources and formulation of dynamical motion equations in different systems using the most general methods (e.g., principle of virtual work, D'Alembert's principle, Newton and Lagrange methods, etc.).
- A complete understanding of the fundamentals of oscillatory systems and their governing nonlinear equations; also analytical and numerical methods in solving applied problems, especially those with nonlinearities.
- A complete study of mathematical problems in engineering, analytic, and numeric methods (e.g., perturbation methods, the homotopy perturbation method, variational methods, energy methods, limit cycles, the parameterized perturbation method, the singular perturbation method, Adomian's decomposition method, the differential transformation method and its modification, He's parameter expansion method, He's amplitude–frequency formulation, the harmonic balance method, the coupled method of homotopy perturbation, the variational method, Floquet theory, etc.).
- Complete familiarity with specialized processes and applications in different areas of the field, studying them, eliminating complexities and controlling them, and also applying them in real-life engineering cases.
- A complete analysis of important engineering systems (e.g., NDOF systems, discs, springs, beams, normal modes, multibody phenomena, shafts, sliders, the human body, nonlinear oscillators in automobile design, rotating rigid frames, flexible beams, rotating rigid hubs, elastic cantilever beams, the human eardrum, etc.).
- A complete analysis of important equations in the field and their generalizations in real-life applications with practical examples (Duffing's oscillation, Van der Pol's oscillation, Mathieu's oscillation, Hamiltonian oscillation, Hill's oscillation, resonances, viscoelasticity, damping, fraction order, cubic nonlinearity, coupled systems, wave equations, etc.).
- The ability to encounter, model, and interpret an engineering process or system and to solve the related complexities engendered by the vibrations property in linear and nonlinear cases.

Audience

This book is a comprehensive and complete text on dynamical and vibratory motions and analytical and numerical methods in applied problems. It is self-contained, and the subject matter is presented in an organized and systematic manner. This book is quite appropriate for several groups of people, including the following:

- Senior undergraduate and graduate students taking courses in the mentioned fields.
- Professionals, for whom the book can be adapted for a short course on the subject matter.
- Design and research engineers, who will be able to draw upon the book in selecting and developing mathematical models for analytical and design purposes in applied conditions.
- Practicing engineers and managers who want to learn about the basic principles and concepts involved in the solving of problems using analytical and numerical methods such as dynamics, vibrations, and systems analysis and how they can be applied at their own workplaces.
- Generally, users who are bachelor's, master's, and Ph.D. students, university teachers, and even researchers at centers in different fields of mechanical, civil, aerospace engineering, applied physics, mathematics, and so forth.

Because the book is aimed at a wide audience, the level of mathematics is kept intentionally low. All the principles presented in the book are illustrated by numerous worked examples. The book draws a balance between theory and practice.

Acknowledgments

We are grateful to all those who have had a direct impact on this work. Many people working in the general areas of nonlinear phenomena, vibrations, oscillations, dynamics, mathematical, and physical problems, and analytical and numerical methods have influenced the format of this book.

The authors are very thankful to Babol Noshirvani University of Technology, Iran, and the National Elite Foundation of Iran (Bonyad Melli Nokhbeghan), Mazandaran Province, Sari, Iran, especially the nonlinear dynamics teams in the Mechanical Engineering Department, and all professors and students of all Iranian universities who helped them develop research skill, editing the electronic text, giving them useful consultation and precious guidance, and providing references for the authors, especially examples of applications that were used in different chapters.

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We are indebted to many colleagues and to numerous authors who have made contributions to the literature in this field. In addition, I am greatly indebted to all the authors of the articles listed in the bibliography of this book, such as Professors Ali Nayfeh, Shaher Momani, Liao, G. Adomian, J. Srinivas, Richard H. Rand, Alexander Fidlin, and other professors for their kind and faithful support and references that were directly used in the writing of this book. I would also like to thank the reviewers for their efforts and for their comments and suggestions, which have well served to compile the best possible book for the intended and targeted audience.

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Finally, we would very much like to acknowledge the devotion, encouragement, patience, and support provided by our family members.

I would appreciate being informed of errors or receiving other comments about the book. Please write to the authors at the Babol Noshirvani University of Technology address or send e-mail to: sha.hashemi.kachapi@gmail.com (Seyed H. Hashemi Kachapi) and ddg_davood@ yahoo.com (D. D. Ganji)

We sincerely hope that the final outcome of this book will help students, researchers, and other users in developing an appreciation for the topic of analysis of nonlinear dynamical systems and nonlinear vibration analysis using analytical and numerical methods.

Contents

Notation and Units

Both the SI and the US/English systems of units have been used throughout the book.