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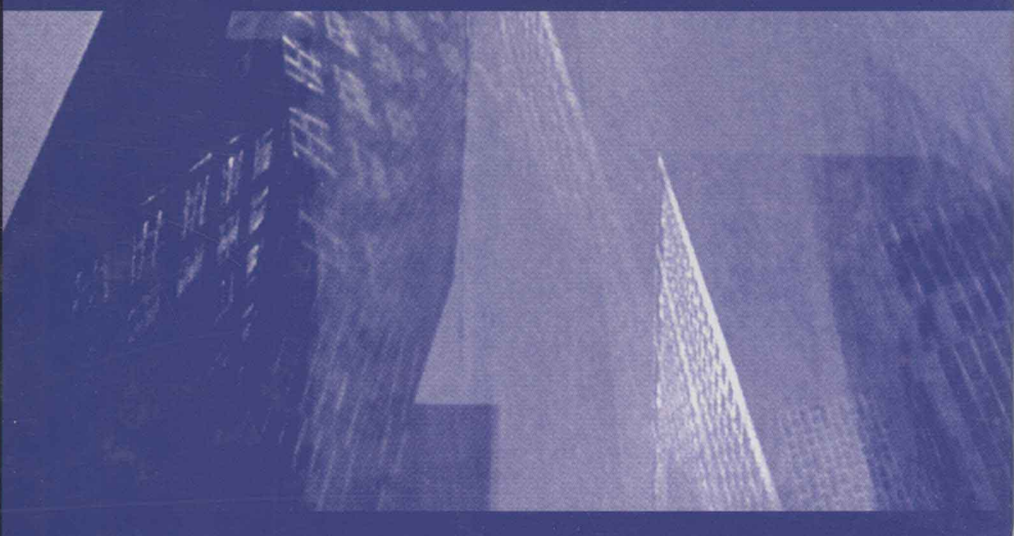
Chee-Kiong Soh • Yaowen Yang
Suresh Bhalla *Editors*

Smart Materials in Structural Health Monitoring, Control and Biomechanics



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Zhejiang University is one of the leading universities in China. In Advanced Topics in Science and Technology in China, Zhejiang University Press and Springer jointly publish monographs by Chinese scholars and professors, as well as invited authors and editors from abroad who are outstanding experts and scholars in their fields. This series will be of interest to researchers, lecturers, and graduate students alike.

Advanced Topics in Science and Technology in China aims to present the latest and most cutting-edge theories, techniques, and methodologies in various research areas in China. It covers all disciplines in the fields of natural science and technology, including but not limited to, computer science, materials science, life sciences, engineering, environmental sciences, mathematics, and physics.

Preface

Smart materials, perhaps the most fascinating category of materials developed in the 20th Century, possess responsive capabilities to external stimuli, enabling them to change their physical properties according to the stimulus. The feedback functions within the materials are combined with the properties and functions of the materials. Smart materials can be either "*active*" or "*passive*". Active smart materials, one hand are those which possess the capacity to modify their geometric or material properties under the application of electric, thermal or magnetic fields, thus acquiring an inherent capacity to transduce energy. Piezoelectric materials, shape memory alloys, electro-rheological fluids and magneto-strictive materials are active smart materials which can be used as force transducers and actuators. Additionally, piezoelectric materials can convert mechanical force into electrical energy, enabling them as sensors or energy harvesters. Passive smart materials, on the other hand, lack the inherent capability to transduce energy, *e.g.*, fiber optic material. Such materials can act as sensors but not as actuators. This book examines both active and passive smart materials in structural health monitoring (SHM), control and bio-mechanics. The book starts with the fundamentals and takes the readers gradually through the mathematical formulations and experimental details.

Chapters 1 to 7 of the book are primarily concerned with the lead zirconate titanate (PZT) piezoelectric material and the electro-mechanical impedance (EMI) technique for SHM. The different impedance models, derived by the book's authors, for health monitoring and damage quantification using PZT transducers are presented. This includes three approaches: extraction of structural mechanical impedance from signatures; identification of higher natural frequencies from signatures; and the use of evolutionary programming. Furthermore, strength and damage assessment of concrete using both surface-bonded and embedded PZT transducers are examined. The extracted equivalent stiffness is used in a framework of fuzzy set theory to spell out a damage quantification approach for real-world concrete structures. An approach to integrate the EMI technique with global vibration techniques is also presented. It is shown that the same PZT patch can serve as the sensor for both techniques. Whereas incipient-level damages can be identified using the EMI technique, the global vibration response of the structure acquired from the same patch with minimal hardware and data processing tools can facilitate the detection, localization and quantification of moderate to severe damage. Finally, several practical issues involving the application of PZT transducers and EMI technique for SHM such as sensing region and load monitoring are discussed.

Chapters 8 to 10 of this book focuse on the control and excitation of structural vibration using piezoelectric transducers. Analytical and semi-analytical solutions for vibration control of smart beams, subjected to axial loads, are derived under different control strategies. The integrated optimization of the control system for smart plates and shells is then formulated and implemented using a modified genetic algorithm (GA). Numerical results illustrate that vibration suppression could be significantly enhanced with the appropriate distribution of piezoelectric transducers and selection of control parameters. Subsequently, the optimal excitation of plates and shells using PZT transducers is demonstrated and a simple, yet general, procedure to determine the optimal excitation locations of the PZT actuators is presented. Finally, the dynamic response of a fully coupled hybrid piezo-elastic cylindrical shell with piezoelectric shear actuators is presented, followed by investigation of the active vibration control of the cylindrical shell.

Use of the passive smart material, fiber optic, as sensors for SHM is covered in Chapters 11 to 13. After a presentation of the theoretical details, real-life applications of fiber Bragg grating (FBG) sensors—the most successful type of fiber optic sensor in the health monitoring of highway bridges and rock and underground structures—are presented. In addition, comparisons between monitoring of rock and underground structures using FBG and electrical strain gauges (ESGs), and FBG and PZT are made.

Use of another active smart material, ionic polymer-metal composite (IPMC), in bio-mechanics is discussed in Chapters 14 to 16. The bending capacity of IPMC is first derived and validated under both dynamic and static electric potentials, followed by the modeling of an IPMC beam on human tissue, an IPMC ring with elastic medium and an IPMC shell with flowing fluid, which represent possible applications of IPMC materials in biomedical engineering. Examples are also used to illustrate the viability of the models. Lastly, application of PZT transducers as bio-medical sensors to characterize bones is presented. The study is verified with finite element (FE) simulation of the EMI technique on bones.

Chapter 17 completes the book by looking into the future use of smart materials. Based on preliminary works done by the book's authors, the future application of IPMC as artificial muscles and organs, and the future application of PZT, macro-fiber composite (MFC) and IPMC for harvesting of ambient energy are envisaged.

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