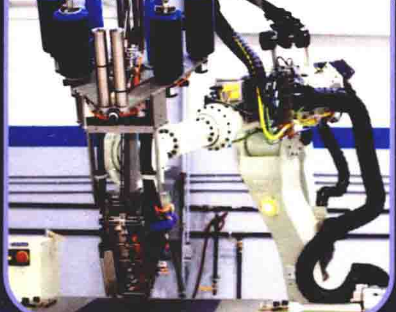
Structural Health Monitoring of Composite Structures Using Fiber Optic Methods

Edited by Ginu Rajan • B. Gangadhara Prusty



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Edited by

Ginu Rajan

The University of Wollongong, Australia

B. Gangadhara Prusty

UNSW Australia

Krzysztof Iniewski MANAGING EDITOR

CMOS Emerging Technologies Research Inc.
Vancouver, British Columbia, Canada

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Foreword

Since the development and deployment of optical fiber for communications in the 1970s, the application of optical fibers as sensors for a wide variety of measurands has been the subject of extensive research and has resulted in the development of a wide variety of sensor types for a vast range of areas, from the macro scale, for example, structural sensing for bridges and other civil structures, to the nanoscale, for biological and chemical sensing.

Compared with conventional electronic sensors, optical fiber sensors offer useful advantages such as high sensitivity, compact size, light weight, immunity to electromagnetic field interference, the capability to work in high-temperature environments, and the potential for remote operation. Optical fiber sensors can be classified as either point sensors, sensing a measurand at a single point, or distributed sensors, in which case sensing takes place in a continuum over distances that can range from centimeters to tens of kilometers.

Composite material structures are widely used in the aerospace, marine, aviation, transport, and civil engineering industries. They offer high strength coupled to light weight by comparison with traditional metal and other alternatives. However, as with all structures, composite structures are frequently subjected to external perturbations and varying environmental conditions, which may cause the structures to suffer from fatigue damage and/or failures. Thus, real-time structural health monitoring is needed in many applications, with the expectation that the structural health monitoring will be possible at all times during the working life of the structure. The goal of structural health monitoring is to detect, identify, locate, and assess the defects that may affect the safety or performance of a structure.

Sensors that are commonly employed for structural health monitoring are resistance strain gages, fiber optic sensors, piezoelectric sensors, eddy current sensors, and micro-electromechanical systems sensors. Traditional nondestructive evaluation techniques such as ultrasonic inspection, acoustography, low-frequency methods, radiographic inspection, shearography, acousto-ultrasonics, and thermography are effective for structural health monitoring of composite materials and structures, but are difficult or impossible to use in an operational structure due to the size and weight of the systems involved. Fiber-optic sensors, on the other hand, are very suitable candidates for structural health monitoring in composite materials during operation, since they are capable of achieving the goals of diagnostics as well as condition monitoring and can be embedded into such structures. Over the last decade and more, fiber-optic sensors embedded in composite structures have been shown to be capable of monitoring stress/strain, temperature, the composite cure process, vibration, thermal expansion, humidity, delamination, and cracking. The potential of optical fiber sensors for condition monitoring of composites has been a major foundation of the emergence of so-called smart composite structures, where the sensors act in many ways as the equivalent of a human nervous system for the material and structures.

This textbook provides a comprehensive overview of structural health monitoring for composite structures using fiber-optic methods. Drawing on the extensive experience of a wide range of distinguished contributors, this textbook covers the variety of topics relevant to structural health monitoring in composite materials. The book opens with a chapter covering the useful prerequisite of fabrication methods in advanced composite structures. The topic of structural health monitoring methods for composite materials in a general sense is then considered to put the use of fiber-optic sensors into a larger perspective. This is followed by an overview of fiber-optic sensors, covering a variety of sensor types and operating principles. In the chapter that follows, more specific coverage of fiber Bragg grating sensors is provided. Fiber Bragg gratings are one of the most common sensor types deployed in composite structures for structural health monitoring by point sensing, offering high sensitivity to strain and a mature, well-understood technology base. While multiple fiber Bragg gratings can be used for sensing at a number of points in a structure, for true distributed sensing, sensors such as polarimetric sensors and sensors based on scattering in fibers are used, and thus, a chapter is dedicated to such sensors. In the next chapter, fiber-optic acoustic emission sensors are addressed. Such sensors are a promising approach to detecting critical precursors to structural failure, such as crack growth and delamination. The complex topic of strain transfer within a composite structure is considered in the chapter that follows, reflecting the real-world importance of a good understanding of how sensors interact with the host material when embedded in composite materials.

Given the rapid rise in the use and applications of composite structures, composite fabrication and production is a topic of great importance. Live monitoring of the production process is increasingly the norm for complex and high-cost composite parts, and a chapter is dedicated to the use of optical fiber sensors for monitoring process parameters such as cure rate and temperature.

The chapters that follow cover a range of very topical and useful application areas for optical fiber sensors. Composite bridges are a novel approach to one of the most common civil engineering structures in use, and a chapter is thus dedicated to their monitoring and evaluation. In the chapter that follows, smart composite textiles with embedded optical fibers are considered. Textiles with embedded sensors are proving to be an attractive development with applications from large scales, in monitoring soil movement, to smaller scales, for sensing in smart clothing for medical applications. The chapter that follows considers the applications of sensors in the aerospace industry, reflecting the massive growth that has taken place in the last decade in the deployment of composites in aircraft to reduce weight and thus lower fuel usage. The subsequent chapter then describes recent advances in sensing in smart fiber-reinforced plastic and fiber-reinforced polymers. Finally, the closing chapter considers the case study of SHM for curved composite structures.

Through a combination of a wide variety of related topics in SHM for composite materials, this textbook is an invaluable reference for those who work with composite materials and structures. The material is suitable for scientists and engineers working in the field as well as undergraduate and graduate students studying or carrying out research in mechanical, mechatronic, structural, biomedical, and electrical engineering.

Professor Gerald Farrell,
Director, Photonics Research Centre
Dublin Institute of Technology, Ireland

Editors

Ginu Rajan is a vice-chancellor's research fellow/lecturer at the University of Wollongong, Australia, and is also a visiting fellow at the University of New South Wales, Australia. He received his BSc degree in Physics from the University of Kerala and MSc degree in Applied Physics from Mahatma Gandhi University, Kerala, India, in 2000 and 2002, respectively. He worked as a researcher at the Indian Institute of Astrophysics during the period 2003–2005. He subsequently undertook research in the area of optical fiber sensors, in which he gained a PhD from Dublin Institute of Technology, Ireland, in 2009.

During 2009–2012, Dr. Rajan worked as a project manager at the Photonics Research Centre of Dublin Institute of Technology in collaboration with the Warsaw University of Technology, Poland, and from 2012–2014 as a research fellow/lecturer at the University of New South Wales. He has published over 120 articles in journals, at conferences, and as book chapters, and two patents are also granted to him. He has also given invited talks at conferences and is a technical program committee member of several conferences in the smart structures and photonics area. He is currently a reviewer for more than 23 scientific journals and also a reviewer for grant applications of the Portugal Science Foundation and Australian Research Council. He is the editor of the book *Optical Fiber Sensors: Advanced Techniques and Applications* and is also an editorial board member of the *Scientific World Journal*. His research and teaching interest includes optical fiber sensors and their applications in biomedical engineering, fiber Bragg grating interrogation systems, photonic crystal fiber sensors, polymer fiber sensors, smart structures, and physics of photonic devices. He can be reached at ginu@uow.edu.au or ginurajan@gmail.com.

B. Gangadhara Prusty is a professor for the University of New South Wales Mechanical and Manufacturing Engineering and leads the School's Advanced Structures and Materials group. He is also the deputy director of the Centre for Sustainable Materials Research Technology at the University of New South Wales.

His research strength is in the mechanics of composites at nano, micro, and macro scales, embodied with the latest analysis and modeling techniques blended with material characterization.

Gangadhara has already contributed to a number of fundamental developments in the field of mechanics of composite materials and structures, such as the novel finite element formulation for stiffened structures, *in situ* monitoring of robotic composite manufacturing, hierarchical multiscale submodeling approach for the onset theory, efficient modeling of barely visible impact damage in post-buckled structures, robust design optimization for layups for shape-adaptive composite propellers, and mitigating creep and cracking in thermoplastic composite welding.

Professor Prusty has led a number of major internationally collaborative projects, such as Systems for Crashworthiness and Robust Optimisation for Imperfection Sensitive Composite Launcher Structures at the University of New South Wales, through external funding. His research is closely aligned with the emerging the

University of New South Wales research strength of next-generation materials and technologies.

Krzysztof (Kris) Iniewski manages R&D at Redlen Technologies Inc., a start-up company in Vancouver, Canada. Redlen's revolutionary production process for advanced semiconductor materials enables a new generation of more accurate, all-digital, radiation-based imaging solutions. Kris is also a founder of ET CMOS Inc. (www.etcmos.com), an organization of high-tech events covering communications, microsystems, optoelectronics, and sensors. In his career, Dr. Iniewski has held numerous faculty and management positions at University of Toronto, University of Alberta, Simon Fraser University, and PMC-Sierra Inc. He has published over 100 research papers in international journals and conferences. He holds 18 international patents granted in the USA, Canada, France, Germany, and Japan. He is a frequent invited speaker and has consulted for multiple organizations internationally. He has written and edited several books for CRC, Cambridge University Press, IEEE, Wiley, McGraw Hill, Artech House, and Springer. His personal goal is to contribute to healthy living and sustainability through innovative engineering solutions. In his leisure time, Kris can be found hiking, sailing, skiing, or biking in beautiful British Columbia. He can be reached at kris.iniewski@gmail.com.

Contributors

Francis Berghmans
Brussels Photonics Team
Department of Applied Physics and Photonics
University of Brussels
Brussels, Belgium

Christophe Caucheteur
Electromagnetism and Telecom Department
University of Mons
Mons, Belgium

Yung William Sasy Chan
School of Civil Engineering
Dalian University of Technology
Dalian, China

Edmon Chehura
Department of Engineering Photonics
Cranfield University
Cranfield, United Kingdom

Bin Chen
Department of Civil Engineering
Zhejiang University
Hangzhou, China

Joris Degrieck
Department of Materials Science and Engineering
Gent University
Gent, Belgium

Chuan-Zhi Dong
Department of Civil Engineering
Zhejiang University
Hangzhou, China

Jayantha Ananda Epaarachchi
School of Mechanical and Electrical Engineering
University of Southern Queensland
Toowoomba, Australia

Thomas Geernaert
Brussels Photonics Team
Department of Applied Physics and Photonics
University of Brussels
Brussels, Belgium

Tamer Hamouda
Textile Research Division
National Research Centre
Dokki, Egypt

Gayan Kahandawa
School of Engineering and Information Technology
Federation University
Ballarat, Australia

Damien Kinet
Electromagnetism and Telecom Department
University of Mons
Mons, Belgium

Nicolas Lammens
Department of Materials Science and Engineering
Gent University
Gent, Belgium

Tan Liu
Department of Civil Engineering
Zhejiang University
Hangzhou, China

Geert Luyckx
Department of Materials Science and Engineering
Gent University
Gent, Belgium

Paweł H. Malinowski
Institute of Fluid–Flow Machinery
Polish Academy of Sciences
Gdańsk, Poland

Patrice Mégret
Electromagnetism and Telecom Department
University of Mons
Mons, Belgium

Hideaki Murayama
Department of Systems Innovation
School of Engineering
University of Tokyo
Tokyo, Japan

Ebrahim Oromiehie
School of Mechanical and Manufacturing Engineering
University of New South Wales
Sydney, Australia

Wiesław M. Ostachowicz
Institute of Fluid–Flow Machinery
Polish Academy of Sciences
Gdańsk, Poland

and

Faculty of Automotive and Construction Machinery
Warsaw University of Technology
Warsaw, Poland

Jinping Ou
School of Civil Engineering
Harbin Institute of Technology
Harbin, China

and

School of Civil Engineering
Dalian University of Technology
Dalian, China

Raju
BMS College of Engineering
Bangalore, India

Dipankar Sengupta
École de technologie supérieure
Université du Québec
Montreal, Canada

Abdel-Fattah M. Seyam
College of Textiles
North Carolina State University
Raleigh, NC

Tomasz Wandowski
Institute of Fluid–Flow Machinery
Polish Academy of Sciences
Gdańsk, Poland

Xiao-Wei Ye
Department of Civil Engineering
Zhejiang University
Hangzhou, China

Zhi Zhou
School of Civil Engineering
Dalian University of Technology
Dalian, China

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