Handbook of Advanced Nondestructive Evaluation

Nathan Ida • Norbert Meyendorf
Editors

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With 949 Figures and 43 Tables

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Preface

The Internet of Things (IoT) and the next generation of industrial production (Industry 4.0) encompass the complete networking of all industrial areas. New production techniques as, for example, 3D printing will allow efficient on-time production of low numbers of unique parts. A significant aspect is quality and maintainability of these (sometimes) unique structures and components. Nondestructive evaluation or testing (NDE or NDT) must, necessarily, follow these trends by not only adapting NDE techniques to new technologies but also introducing the capability of cyber systems into the inspection and maintenance processes and anticipating future needs. These new challenges and capabilities will also boost the application of unconventional and new NDE principles to industrial applications.

Industry 4.0 and the ability to tailor individual components to the customer's needs will significantly impact the way we provide nondestructive inspection and evaluation. NDE must be integrated into the production process by networking with processes and production steps during manufacturing. This will result in a paradigm shift in industrial quality management and NDE. Classical concepts based on comparison of multiple similar components and statistical analysis will not be applicable under these conditions, raising the impact of the human factor. Availability of specialists capable of making the right decisions based on NDE results, knowledge about the material and the components, loading conditions, and NDE modeling of NDE experiments will be essential for the future.

This new generation of NDE specialists need to have a broad overview of conventional and new, advanced NDE techniques. A considerable amount of overview literature for common NDE techniques that are usually based on standards is available worldwide. Several organizations offer NDE training classes and certification for inspectors for the standard techniques. Other new methods that may, at present, be in experimental, laboratory stages but have the potential for application for future inspection tasks can only be found in specific scientific journals and, sometimes, may not even be considered as NDE candidates. However, to solve future NDE tasks, the specialist should have a clear understanding of what is possible without going into too many details.

The present book intends to bridge this gap between conventional common sense NDE methods of the present and the past and advanced techniques that provide and guide new opportunities for inspections for the next generation of NDE. As is often

the case, many methods described here have evolved from prior experience and from pressing needs in industrial inspection. The reader will find that the offerings in the present handbook is a healthy mixture of methods that are in limited use, those that are at various stages of development and some that are envisioned for the future.

This handbook is structured on the lines of accepted NDE principles but focuses on advanced methods of measurement or data analysis. It is not the intent of the book to introduce the basics of NDE principles. The exceptional contributions that make up this handbook were made by specialists worldwide working on advanced NDE techniques. The editors are grateful that so many excellent contributions have been submitted and are happy to present this unique overview of advanced NDE techniques. The task of keeping up to date, of course, can never be completed and any attempt at doing so can only be a snapshot of present activities. In this spirit, the online version of the handbook will be updated and enlarged in the future to keep the contents up to date.

We sincerely thank all those involved in the writing, editing, and production of this work.

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About the Editors

Nathan Ida is currently distinguished professor of Electrical and Computer Engineering at The University of Akron in Akron, Ohio, where he has been since 1985. His current research interests are in the areas of electromagnetic nondestructive testing and evaluation of materials at low and microwave frequencies with particular emphasis on theoretical issues, on all aspects of modeling and simulation and on related issues stemming from research in NDE. Starting with modeling of eddy current and remote field phenomena, and continuing with high frequency methods for microwave NDE, his work now encompasses the broad aspects of computational electromagnetics where he has contributed to both the understanding of the interaction of electromagnetic fields with materials and the development of new methods and tools for numerical modeling and simulation for, and beyond, NDE. Other areas of current interest include electromagnetic wave propagation, theoretical issues in computation, as well as in communications and sensing, especially in low power remote control and wireless sensing. Much of this work has found its way into practice through industrial relations and consulting across industries as diverse as power generation, polymers, steel, medical, and software, spanning the globe. Dr. Ida has published extensively on electromagnetic field computation, parallel and vector algorithms and computation, nondestructive testing of materials, surface impedance boundary conditions, sensing, and others, in over 400 publications. He has written nine books: two on computation of electromagnetic fields (one in its second edition), one on modeling for nondestructive testing, one on nondestructive testing with microwaves, a textbook on engineering

electromagnetics (now in its fourth edition), a textbook on sensing and actuation (now in its second edition), a book on the use of surface impedance boundary conditions, and others, including on ground penetrating radar and industrial sensing based on microwaves. Dr. Ida is a life fellow of the Institute of Electric and Electronics Engineers (IEEE), a fellow of the American Society of Nondestructive Testing (ASNT), a fellow of the Applied Computational Electromagnetics Society (ACES), and a fellow of the Institute of Electronics and Technology (IET). Dr. Ida teaches electromagnetics, antenna theory, electromagnetic compatibility, sensing, and actuation, as well as computational methods and algorithms.

Dr. Ida received his B.Sc. in 1977 and M.S.E.E. in 1979 from the Ben-Gurion University in Israel, and his Ph.D. from Colorado State University in 1983.

Norbert Meyendorf retired in fall 2018 as deputy director of the Center for Nondestructive Evaluation and professor in the Aerospace Engineering department at the Iowa State University in Ames, Iowa. Before joining ISU in 2016 he had several appointment and ranks. The most recent are:

Branch Director at the Fraunhofer Institute for Nondestructive Testing IZFP and later IKTS, director of the International University of Dayton/Fraunhofer Research Center at the School of Engineering at the University of Dayton, organizing collaborative projects between Fraunhofer and University of Dayton, and Program Director of the Master program "Nondestructive Testing, M. Sc. (NDT)" at the Dresden International University (DIU) between 2011 and 2015.

Norbert Meyendorf continues to be active as adjunct professor for micro- and nano-NDE at the University of Dresden and adjunct professor at the Department for Chemical and Materials Engineering, University of Dayton.

He is the author or coauthor of more than 300 peer-reviewed journal articles, contributions to edited proceedings, technical reports, and numerous oral presentations on conferences, meetings, workshops, etc. He is editor in chief of the *Journal of Nondestructive Evaluation* and edited several books and conference proceedings.

His areas of expertise include solid state physics and physical analytics, welding metallurgy, materials testing, nondestructive evaluation (NDE), and structural heath monitoring (SHM), for instance.

Since 2001, he has been chairman or co-chairman of several conferences within the SPIE International Symposium on Nondestructive Evaluation for Health Monitoring and Diagnostics and later the Symposium for Smart Structures and NDE. In 2005, 2006, 2012, and 2013, he was chair or co-chair of the whole SPIE Symposium. In 2018 he became fellow of SPIE.

Norbert Meyendorf was founder and chair of two expert committees of the German Society for Non-Destructive Testing (DGZfP), the Expert Committees for "Structural Health Monitoring" and "Materials Diagnostics." Between 2016 and 2018, he reorganized and directed the ASNT Section Iowa.

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