

PREFACE

For over sixty years, the nondestructive testing (NDT) or nondestructive evaluation (NDE) of materials has been an area of continued growth. The need for NDT has increased dramatically in recent years for various reasons such as product safety, in-line diagnostics, quality control, health monitoring, and security testing, etc. Besides the practical demands the progress in NDT has a lot to do with its interdisciplinary nature. NDT is an area closely linked to aerospace engineering, civil engineering, electrical engineering, material science and engineering, mechanical engineering, nuclear engineering, petroleum engineering and physics among others. There are at least two dozen NDT methods in use. In fact any sensor that can examine the inside of material nondestructively is useful for NDT. However the ultrasonic methods are still most popular because of its capability, flexibility, and relative cost effectiveness. For this reason this book places a heavy emphasis on the ultrasonic methods which are covered in Part I of the book. Many other or advanced methods of NDT have also been well developed in recent years, such as the use of terahertz waveforms, the thermography method, etc. and they are covered in Part II of the book. The application of signal and image processing to NDT problems is another major development in the last twenty years and the subject is presented in Part III. The NDT area is so broad that the representative chapters as presented in the book can cover only certain aspects of the progress and development. However the book is intended to present the essential aspects of the NDT with the chapters authored by leading experts in the field.

We like to emphasize that the book provides a balance between the basics and the applications of NDT. Chapter 1 of Part I on “Fundamental models and measurements for ultrasonic nondestructive evaluation systems by Prof. Schmerr has the most clear and concise presentation of the mathematical principles of characterizing an ultrasonic nondestructive flaw measurement system, which are useful for both medical and industrial evaluations. Combining the ultrasonic beam models, flaw scattering models and measurements in a complete ultrasonic measurement model gives us the capability to make absolute predictions of the measured A-scan signals seen in ultrasonic flaw measurements. Chapter 2 on

“Integrated and flexible high temperature piezoelectric ultrasonic transducers” by Dr. Jen, et al. presents a technology to fabricate flexible transducers consisting of a thin substrate, a piezoelectric film and electrodes. The integrated transducer can operate at high temperature. The flexibility is realized owing to the porosity of piezoelectric film and the thinness of substrate and electrodes. Chapter 3 on “Real-time and in-line ultrasonic diagnostics of polymer process” by Dr. Jen, et al. shows ultrasonic diagnostic capability in polymer extrusion melt quality monitoring application. Also for injection molding diagnostics filling monitoring is illustrated. Laser-ultrasound is a major development in ultrasonic NDE in recent years. We are fortunate to have Dr. Jean-Pierre Monchalin to write Chapter 4 on “Laser ultrasonics: principles and industrial applications”, which provides a broad overview of the field of laser-ultrasonics encompassing basics and applications. This chapter is a “must” reading for students and researchers in the laser ultrasound area. Another major new development in ultrasonic NDT is the methodology of guided waves as described in Chapter 5, “Guided wave based nondestructive testing: a reference-free pattern recognition approach”, by Dr. Sohn, et al. Defects such as crack and/or corrosion can be detected without requiring pattern comparison with previously stored baseline data. The robustness of the proposed technique against undesirable variations in the system, such as temperature and external loading, can be attractive for long-term continuous monitoring.

A unique feature of this book is that it deals with both industrial and medical ultrasound. The latter is covered in the next four chapters. Both Chapter 6 and Chapter 7 by Dr. Zhang and Dr. Yan et al. respectively are focused on the tissue harmonic imaging based on the second harmonic ultrasound propagation. Chapter 8 on “Applications of high-frequency ultrasound to diagnostic and regenerative medicine” by Dr. Walters starts with a discussion of propagation and scattering properties of soft tissue and then presents a high frequency ultrasound system using 50 MHz transducer for the study of pulmonary arterial hypertension. This study can be important to the diagnosis and treatment of coronary arterial disease. An important advantage of the ultrasonic system is that it can be quantitative and noninvasive or minimally invasive. Chapter 9 is concerned with the receiver operating characteristics (ROC) analysis for computer aided detection. Both threshold specific performance measure such as sensitivity and specificity, and threshold independent performance measure based on the area under ROC curve are examined. The use of ROC curve is not limited to medical ultrasound problems however. Recently there has been greatly increased interest in ROC analysis for NDT problems in general. Finally the last

chapter of Part I, “Waveguides in acoustic sensor systems” by Larry Lynnworth is one of the few chapters of the book dealing with ultrasonic NDT devices.

The development of new sensors or emerging methods of nondestructive testing has contributed greatly to the advances of NDT. Part II deals with advanced methods other than ultrasound for NDT. It begins with Chapter 11 on “Electromagnetic NDE techniques for materials characterization” by Dr. Jayakumar et al. which provides an excellent overview of eddy current, magnetic, micro-magnetic, alternating current field measurement (ACFM), potential drop and microwave techniques for material characterization. Terahertz waveforms represent a new method for NDT. Chapter 12 “Terahertz NDE for aerospace applications” by Bob Anastasi, et al. presents the pulsed terahertz technology which is an excellent example of emerging techniques that provide nondestructive testing of difficult-to-inspect material such as the Sprayed-on Foam insulation of the Space Shuttle External Tank. Terahertz NDE is useful also for metallic surface roughness evaluation and characterization of corrosion under paint and corrosion under shuttle tile. Chapter 13 is “Large area time domain terahertz (T-Ray) imaging non-destructive evaluation for security and aerospace” by Dr. Zimdars, et al. T-ray imaging employs single cycle sub-picosecond electromagnetic impulses with hyper wide band spectral content spanning the millimeter-wave to terahertz region of the spectrum. T-Ray imaging can offer up to 10 to 50 times greater resolution than microwave imaging at 40–90 GHz. There are other advantages offered by this new technology as presented in this chapter.

The next three chapters deal with the thermography technique in NDT. Chapter 14 on: “Active infrared thermography techniques for the nondestructive testing of materials”, by Dr. Clemente Ibarra-Castanedo et al. provides an overview of three active thermography techniques including lock-in thermography, pulsed thermography and vibrothermography, which have various capability in speed and depth of penetration. The next chapter on “Quantitative evaluation of emerging infrared thermography techniques for aerospace applications” by Dr. DiMambro is emphasized on the sonic infrared probability of detection study using titanium specimens. Sonic Infrared Imaging is an emerging inspection technology that employs short pulse of ultrasound, typically less than a second, via a 20–40 kHz ultrasonic transducer. The increase in temperature in the vicinity of crack in aircraft components being tested can then be detected with an infrared camera. Further to the discussion of this subject is the next chapter on “Sonic infrared imaging: a novel NDE technology for detection of crack/delaminations/disbands in materials and structures” by Prof.

Han, which provides further physical insights and capability of the sonic infrared technology.

Chapter 17, “A data fusion framework for interpreting multiple NDT images” by Dr. Liu, et al. represents another major research in interpreting NDT data. As more than one sensor is likely to be used in NDT nowadays, the basic question is how to best integrate the information from different sensors. In this chapter an image fusion framework for interpreting NDI images based on Dempster-Shafer (DS) theory is presented. The use of DS theory to fuse the inspection results of aircraft lap joints with conventional eddy current and pulsed eddy current is demonstrated. The list of 30 references will help readers to gain more insight of the NDT data fusion approaches in general.

Although most NDT work has an objective of health monitoring or structural health monitoring, the next three chapters deal specifically with the issue of structural health monitoring. Chapter 18 on “SMART structures approach: achieving global structural health monitoring through the application of distributed, embedded micro-sensor systems”, by Dr. Roach presents a clear introduction to the needs and approaches in structural health monitoring with special reference to the aging infrastructure. The application of distributed sensor systems can reduce the costs involved by allowing condition-based maintenance practice to be substituted for the current time-based maintenance approach. It may be possible in the near future to quickly, routinely, and remotely monitor the integrity of a structure in service. The next chapter, “Nondestructive testing for bearing condition monitoring and health diagnosis” by Prof. Gao, et al. is concerned with diagnosing the health condition of rolling bearings. Commonly used NDT techniques based on mechanical and acoustic sensing are reviewed. Vibration has been shown to be an informative and convenient variable for revealing bearing conditions. Bearing can be measured by using displacement, velocity, and acceleration sensors. The strength and weakness of the sensing techniques are examined. The authors also mentioned of the recent advancement of wireless sensor networks for NDT that allows for distributed sensing and improved decision making. This idea of integrating sensors is clearly shared by the following chapter, “Advanced sensors for health monitoring systems” by Dr. Mrad. This chapter presents non-mathematically the key sensor technologies which are integrated within an aircraft diagnostics, prognostics and health Management (DPHM) system making use of the fiber-optic based sensor networks.

Part III of the book is on the use of signal and image processing in the NDE problems. This is an area that has made progress for over twenty years and its importance is gaining attention gradually especially since the publication of my

edited book, "Signal Processing and Pattern Recognition in Nondestructive Evaluation of Materials", Springer-Verlag 1987. Clearly the area has many different approaches that may not be well correlated. Chapter 21, "Computational intelligence methodologies for non destructive testing/evaluation applications", by Dean Morabito, et al. describes how the advanced signal processing techniques, such as wavelet transform and independent component analysis, broadly listed as the computational intelligence methods, can be used in solving NDT problems such as feature extraction, denoising, identification of defects, etc. Perhaps the most influential signal processing development for NDT is the split spectrum processing (SSP). The following chapter, "Spit spectrum processing and automatic flaw detection" by Prof. Donohue has the most extensive but concise treatment of the subject from mathematical principles to the examples demonstrating the application of SSP in an automatic flaw detection scheme for multiple flaws embedded in nonstationary grain noise. The nonlinearities of the SSP algorithm effectively change the flaw and grain echo distribution to enhance the separation of their amplitudes beyond that of simple envelope detection. The ultrasonic nondestructive characterization of thin layered composite materials or structures can be difficult because the reflected signals are highly overlapped. The classical signal processing approach would have difficulty to separate the layers and determine the thickness and velocity of each layer. Chapter 22, "An application of the EM algorithm to thickness estimation of thin layered materials" by myself and X. Wu presents the use of expectation-maximization algorithm that is robust and effective to estimate layer thicknesses. It is noted that like in any signal processing problems, the quality of available data has a lot to do with the final signal processing performance. However signal processing allows us to extract information not easily available from the NDT measurements and thus essentially extend the resolution of the measurement beyond what is offered by the physical system. The actual signal processing effect may depend on the individual problem under consideration. The next chapter, "Homomorphic devonvolution of ultrasonic images" by Dr. Jirik et al. addresses the basic 1-D and 2-D deconvolution issues with examples of medical ultrasonic images. They are able to demonstrate that the images of kidney and aorta are sharper and more precise after homomorphic deconvolution.

Signal and image processing can help the human users to get a better visualization of the damage as clearly illustrated in Chapter 25 on "Frequency-wavenumber domain filtering for improved damage visualization" by Prof. Ruzene. The chapter presents a filtering technique aimed at improving the damage visualization capabilities of full wavefield measurements. The technique operates in the frequency/wavenumber domain, where the presence of reflections

associated to damage can be easily observed and separated from the main signal generated for inspection. Chapter 26 on “Recent advanced signal processing methods for waveform-based NDE methods” by Dr. Roth, et al., focuses on developing broad-based signal and image processing software for terahertz waveforms as used in the nondestructive evaluation of foam-based thermal protection system of NASA’s Space Shuttle external tank. Some novel ideas of waveform feature extraction for image generation are presented. For example, the centroid of the power spectral density for the main (substrate) reflection off a metallic substrate under the foam shows promise versus conventional parameters of the signal used to form images. One of unique aspects of the software is the inclusion of a merit assessment algorithm to “grade” various signal processing methods. Finally in Chapter 27, “A Robust algorithm for nondestructive testing of weld seams”, by Dr. Mery, et al. provides a detailed survey of available image segmentation algorithms suitable for NDT of weld seams. The steps of a proposed algorithm are presented and a quantitative performance measure of the algorithm is shown with the use of ROC curves. Both Chapters 26 and 27 show details of experimental results with the use of signal and image processing algorithms.

The nature of an edited book like this with a collection of articles from leading experts is not the same as journal or conference publications. NDT journals and conference proceedings may not have the details as presented in this volume. Topics of the book have been organized in such a manner that the readers can easily seek for additional and relevant information from a vast number of references cited. I hope the book can contribute in a small way toward the rapid progress of the ultrasonic and advanced (other) methods of nondestructive evaluation. Though the book is an outgrowth of the workshop of the same title held in June 2006 at our campus, and sponsored by our Ultrasonic NDE Lab., the detailed content is quite different. Readers may obtain a copy of the proceedings of the June workshop from the July 2006 issue of NDT e-Journal available from www.NDT.net.

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Finally my special thanks go to all authors of the book whose work as presented in this volume, I firmly believe, can add significantly to the continued growth in NDT.

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