Springer Series in Wood Science

Voichita Bucur

Acoustics of Wood

Second Edition

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2nd Edition

With 202 Figures and 126 Tables

Springer

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Cover: Transverse section of *Pinus lambertiana* wood. Courtesy of Dr. Carl de Zeeuw, SUNY college of Enviromental Science and Forestry, Syracuse, New York

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To the memory of Dr. R.W.B. Stephens
a pioneer in ultrasonic activity
and an enthusiastic stimulator
of creative ideas in acoustics

Preface to the Second Edition

Considerable activity in the acoustics of wood has occurred since the first edition of this book in 1995. An informal survey of a number of the published articles and papers presented at international conferences revealed that the interest of the wood science community is continually increasing. In this context, I felt compelled to revise the text in accordance with newer findings and this prompted the addition in the present book of 159 new references added to the existing 850 in the first edition.

As a result of the favorable comments upon the first edition, from students and colleagues, I have included a part on mathematical theory related to wave propagation in orthotropic solids in the general text, in order to enable the interested reader to follow the essentially physical aspects of the subject. A new chapter related to "acousto-ultrasonics" is introduced; Chapters 4, 5, 6, 8, 9, 10, 11, and 12 have been considerably expanded and a significant redistribution of the subject matter from the earlier edition has been made.

I owe special thanks to Professor Timell who encouraged me to produce this second edition. My gratitude is also addressed to Professor Frank Beall for revising the new chapter related to acousto-ultrasonics, and for his interest in my research activity. I am particularly grateful to Dominique Fellot, who, after reading the first edition from cover to cover, furnished me with long lists of comments, corrections, and suggestions for a better understanding of the text by a reader interested in acoustics, but not a specialist in wood science.

I am especially pleased to acknowledge the help of Marie-Annick Bruthiaux, librarian at the Université Henri Poincaré in Nancy, and Marie Jeanne Lionnet and David Gasparotto, librarians at ENGREF (Ecole Nationale des Eaux et Forêt de Nancy) for their generous contribution with new references. I was also fortunate in securing once again the talented services of Constantin Spandonide who prepared the electronic version of the figures. I wish to express my appreciation to him.

The permanent help of my colleague Dr. Laurent Chrusciel is gratefully acknowledged for preparing the electronic version of the pages of the manuscript. Bruno Spandonide is also acknowledged for help with the electronic version of the book. Corinne Courtehoux and Yvonne Sapirstein are thanked for their everyday help and assistance during the writing of this book.

I wish to express my appreciation to Dr. Adrian Hapca, former Ph.D. student in our laboratory, for the many stimulating discussions which we have had during the past 3 years and which have been of great help to me in presenting this book to the publisher in a modern electronic version. I wish to extend my thanks to my colleagues and former students, institutions, and individuals cited in this book for their permission to use the figures and tables which appear here. Once again, my sister Despina Spandonide was a great help with her encouragement in preparing this manuscript, for which I am very grateful.

Finally, I wish to thank INRA (Institut National de la Recherche Agronomique) Forestry Research Center in Nancy, the Laboratoire d'Etudes et Recherches sur le Matériaux Bois, and director Professor Xavier Deglise for supplying the facilities and support necessary for the preparation of this book.

I would like to thank the editorial and production staff of Springer-Verlag for their very efficient and pleasant collaboration during the time needed to transform the manuscript into the finished book.

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Permission for the figures and tables cited in this book from the journals: Ultrasonic, J. Sound and Vibration, Applied Acoustics are granted by Elsevier and by the American Institute of Physics for the figures and tables cited from J Appl Physics and J of Acoustical Soc America. I am also indebted to the long list of different organizations and individuals cited in this book for their kind permission to reproduce figures and tables.

Nancy, France, September 2005 Voichita Bucur

Preface to the First Edition

My involvement in the project that led to the publication of *Acoustics of Wood* began in 1985 when I first participated in a lecture at the International School of Physical Acoustics organized in the splendid and magical place called Erice in Sicily (Italy), on the subject of ultrasonic methods in evaluation of inhomogeneous materials. The interest of the participants in the subject and the successive invitations addressed to me by Professor Alippi to give "advanced research lectures" in the third and fourth courses at the School in Erice enhanced my idea that a book on wood acoustics could be helpful for scientifically educated persons wishing to know more about wood, as a natural composite material.

All these ideas became a reality with the continuous encouragement of Dr. Carleen M. Hutchins, fellow of the Acoustical Society of America and permanent Secretary of the Catgut Acoustical Society, with whom I have worked very closely over the years on the subject of the acoustical properties of wood for violins and other musical instruments.

The aim of this book is to present a comprehensive account of the progress and current knowledge in wood acoustics, presented in the specialized literature from the last 25–30 years. For earlier publications, the reader is generally referred to books related to wood technology and wood physics.

This book is divided into three main parts. The first part describes environmental acoustics, the second part presents acoustic methods for the characterization of the elastic behavior of wood, and the third part deals with acoustic methods for wood quality assessment. To enhance the usefulness of the book a cumulative index of subjects is presented in the last chapter.

The reader is guided to examine the subject thoroughly by nearly 800 bibliographic references. The compilation of the bibliography using different databases (CAB abstracts, Compendex, Inspec – Physics, Ismec, Nasa, Pascal, Cris, USDA, etc.) was carried out with the kind cooperation of M. Michel Dumas, the librarian at our institute.

During the last 15 years, my colleague Pierre Gelhaye has drawn numerous figures for the slides I needed for my lectures at international conferences and symposia. Almost all of them became figures in this book. It is through his generous help that the book was illustrated.

I am very much indebted to the following people for reading the manuscript and making comments for the improvement of the comprehension of the expressed ideas and written text: Dr. Martin Ansell, University of Bath, UK, Professor I. Asano, University of Tokyo, Japan, Dr. Claire Barlow, University of Cambridge, UK, Dr. Ioan Facaoaru, RILEM and CRL Comp., Vicenza, Italy, Dr. Daniel Haines, Catgut Acoustical Society, USA, M. Maurice Hancock, Catgut Acoustical Society, UK, Dr. Johannes Klumpers, Centre de Recherches Forestières de Nancy, France, Dr. Robert Roos, Forest Products Laboratory, Madison, USA, and Dr. John Wolf, Naval Research Institute, Washington, USA

Last, but not least, I would like to thank to Professor Adriano Alippi, Università di Studi di Roma et Instituto di Acustica di Roma, for his enthusiastic support during obscure and doubtful moments spent writing this book.

I am indebted to the Institute National de la Recherches Agronomique – INRA, France, for providing the facilities required to complete this book, particularly to my colleagues at the Forestry Research Center in Nancy and my students and professional friends mentioned in the bibliographic list.

Thanks are due to my sister Despina Spandonide and to my family, and to all my friends all over the world who followed the writing of this book with interest. Finally, I would like to thank the editorial and production staff at CRC Publishers for their contribution to the heavy task of transforming the manuscript into the finished book.

Foreword

Hooke's law of elasticity

$$[\sigma_{ij}] = [C_{ijkl}]\,[\varepsilon_{kl}]$$

appears in its general form as Eq. (4.1) at the beginning of this book, as it usually does in many texts on elasticity or acoustics. In order to thoroughly appreciate the spirit that inspired the author in writing the *Acoustics of Wood*, one should have seen the very same formula projected by Professor Bucur on the screen of one of the Erice lecture halls during the presentation of an advanced research lecture (as the author herself quotes in the Preface to this book), in a few, elegantly handwritten letters which filled the whole screen in a symphony of pastel colors. The attention of the audience was gently captured. Science and art were locked together by a simple formula, as science and art link together in the author's life, as science and art frequently share a common fate in wood history.

The making of violins, cellos, pianos, and other musical instruments was an art long before being an object of scientific investigation. Architectural wood structures are artists' representations that rely on the advanced achievement of mechanics. The scientific knowledge of wood properties and characteristics is a necessary step toward its best use in artistic representations. This may be a rather personal interpretation of the reading of the book, but could in reality be one of the ways to approach its reading.

The acoustics of wood deals with all aspects of wood that are of concern to acoustics, from sound barriers produced by forests and trees, to the use of wood in acoustical panels; from the crystallographic symmetry classes of different woods, to surface wave propagation in wood structures; from the influence of aging and moisture on elastic propagation in wood, to the chemical methods of improving acoustic properties; from the counting of the average ring width in violin tops, to the high Q properties of guitar wood for sustaining "sing" modes; from acoustic micrographs of acoustic microscopy techniques, to the characteristics of the acoustic emissions of different wood species.

The acoustics of wood, however, primarily needs information about wood, from seed germination to forest growth, including moisture content, aging, and anatomical properties. The intrinsic coordinate system of wood is a cylindrical system that follows the axial direction of growth of the stem, in azimuthal and radial directions; the most common case of wood materials presents an orthotropic symmetry, where three mutually perpendicular mirror planes of symmetry exist, related to the direction of growth. Velocity of ultrasonic waves presents a wide spread of values, from 6,000 m/s for longitudinal waves along the fiber direction to 400 m/s for shear waves in the radial-tangential plane.

An interesting general review of wave equations and solutions accompanies Part II devoted to material characterization, where elastic constant relations to technical constants is duly reviewed together with Christoffel's equations and

eigenvalue properties of the wave equation. That is the science part, as we said at the beginning, which matches with the technical part reported as the last section of the book, where probing of materials and common techniques of testing are also reviewed. All is treated with meticulous care as to completeness and with careful attention to biographical sources, which are listed at the end of the book. Art and style are blended with science, and this is materially achieved with a series of color plates properly selected to show grain and fiber structure in different samples.

Wood is technically studied because of its importance in the manufacture of musical instruments: what are the characteristics of a guitar plate or of a harp sound box or a violin bow and which wood species should be used? Names with exotic charm like Manilkara, Mauritius ebony, and Pernambuco wood alternate with those of cultural Latin origin, such as *Picea abies* and *Acer pseudoplatanus*. Furthermore, they are of interest because of their Young's modulus, Poisson's ratio, or high quality factor.

What was known about quality factors or Poisson's ratio by the handcraft masters of the past? Why is wood still the best material for many musical instruments, not overtaken by the ubiquitous power of plastics? Perhaps Nature is science and art at the same time, and we usually follow different routes to get to the target, only to discover at the end that it could have been achieved by either route.

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