Seismic Ray Theory

Vlastislav Cerveny

The book Seismic Ray Theory by V. Cerveny is concerned with the theory of high-frequency body wave propagation in an inhomogeneous, anisotropic elastic solid. The book is the most complete description of this topic that is currently available. The author is exceptionally well qualified to write such a book as he has made many fundamental contributions to the material covered.

The book is comprised of six chapters. The first provides a brief overview of the book. In Chap. 2 the elastodynamic equations of motion in an inhomogeneous, anisotropic 3-d elastic medium are introduced. Elementary plane wave solutions and Green’s function solutions are discussed, and the equations governing high-frequency asymptotic wave motion are systematically developed. Anisotropy, first introduced here, remains a central theme throughout the book. Chapter 3 is concerned with the solution to the coupled ray and travel-time equations in 3-d environments. Chapter 4 develops dynamic ray tracing wherein the evolution of ray variational quantities following ray trajectories is described. The propagator matrix is introduced. Chapter 5 is concerned with the calculation of ray amplitudes. Included are discussion of Gaussian beam summation methods and the Maslov–Chapman integral. Chapter 6 is concerned with the time domain—the construction of the transient response, a synthetic seismogram, to transient forcing.

All of the material presented is developed from basic concepts, so the reader need not have any a priori knowledge of ray methods or waves in elastic solids. A moderately strong mathematical background (familiarity with complex variables, integral transforms, and vector and tensor calculus) and some knowledge of basic continuum mechanics is assumed, however. While some mathematical skill is required, Cerveny does a good job of keeping the focus on the physics, not allowing the mathematics to become a distraction. The focus of the book is clearly and consistently on the theory of ray methods in seismic wave propagation. The theory behind some numerical methods is discussed, but numerical methods are themselves not a focus. Practical issues relating to seismic data interpretation are not considered. The choice of material covered is fairly traditional with an emphasis on results that are needed to solve seismic body wave problems. Some less traditional topics such as ray chaos, the catastrophe classification of caustics, and the use of space–time rays to model surface (Rayleigh and Love) wave propagation problems are discussed, but only very briefly.

Two clear strengths of the book are its treatment of elastic media, including anisotropy and dissipative effects, and its treatment of the time domain, i.e., the construction of synthetic seismograms. The strong focus on transient wavefields is not surprising, as in seismic applications fixed frequency wavefields are of interest only insofar as they can be used to construct transient wavefields. Sadly, the time domain is poorly treated in many books on acoustics, and is poorly understood by many acousticians.

Readers interested primarily in the application of ray methods to sound propagation in fluids might be frustrated by the strong focus of the book on elastic media. The acoustic problem is, of course, a special case, but some fluid-specific problems such as sound propagation in the presence of background flow are not treated. Also, there is no treatment of wave propagation in fluid-saturated porous elastic media; marine sediments are often treated using models of this type. The scattering of sound by discrete elastic objects is also not considered in the book; ray methods are very useful in this context as well.

The comments above about omitted topics should not be interpreted as a criticism of the book; rather, they should be interpreted as a warning to potential readers and purchasers of the book not to expect an encyclopedic survey of ray methods. Overall, I think that Cerveny’s choice of topics covered is quite sensible in that it allowed him to maintain a clear focus throughout the book.

The style of the book is simultaneously that of textbook and monograph: textbook because all results presented are derived from basic principles; and monograph because the results presented are current and the bibliography extensive. There are no exercises, however, so the utility of the book as a textbook is limited.

Cerveny is a distinguished scholar who has made many fundamental contributions to the study of seismic body wave propagation, especially in the area of Gaussian beam summation methods. Because of his stature and considerable experience, I would have welcomed a more critical discussion—even if it were biased—of different ray-based methods, and ray methods generally. For instance, the Maslov–Chapman wavefield representation is described and its connection to a Gaussian beam sum is noted, but there is no discussion of the relative advantages and disadvantages of each representation.

Seismic Ray Theory is ideally suited to researchers, including graduate students, whose work involves the interpretation of body wave seismograms. Indeed, for this group, I think that Seismic Ray Theory would be an indispensable reference. I expect that even experienced body wave seismologists would likely learn a great deal from reading the book. The book is also well suited to researchers in other fields who want to learn about how ray methods are applied in seismic applications. The book could be used as a textbook in an advanced graduate level course on seismic ray methods, or portions of the book could be assigned as supplementary reading in an introductory graduate level course on theoretical seismology. Its utility as a textbook is somewhat limited, however, by the lack of exercises.

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Fundamentals and Applications of Ultrasonic Waves

David Cheeke

We learn from the Preface that Cheeke has written this book as a text for senior or graduate and graduate students in a one semester course in ultrasonics. He starts with a chapter giving an overview of ultrasonics covering the history of the subject and outlining its principal divisions. This should be useful to beginning students and specialists in other fields. The second chapter takes us into the basics of vibrations, including a brief sur-
quality of Fourier theory. Wave motion is introduced using the string in vibration, not usually regarded as an ultrasonic phenomenon. We then move onto three-dimensional waves, dispersion, group velocity, and wave packets. Chapter 3 examines bulk waves in fluids starting with a derivation of the one-dimensional wave equation. There are discussions of the velocity in gases and liquids based on physical theories, and then impedance, energy density, and intensity are introduced. Poynting vector, attenuation due to viscosity, and attenuation are discussed finishing with the concept of relaxation. Chapter 4 brings us to the theory of elasticity. Starting with a review of tensor analysis we proceed through the strain and stress tensors and then the generalized form of Hooke's law, finishing by determining equivalencies of tensor analysis we proceed through the strain and stress tensors and then the generalized form of Hooke's law, finishing by determining equivalencies of tensor analysis. Advanced mathematical presentations such as this are not usually found in ultrasonic texts. Chapter 5 takes us into the elastodynamics of bulk acoustic waves in solids. The presentation starts with one-dimensional waves and then an extension of the argument to three dimensions using analogies from electromagnetic theory. There is a useful discussion of material properties including a descriptive treatment of attenuation theory from solid state physics. Chapter 6 covers radiation theory with an emphasis on problems related to ultrasonic beams. It begins with the spherical source, and continues into a discussion of the circular piston radiator. There are descriptive treatments of scattering, focussed acoustic waves, radiation pressure, and the Doppler effect. A rather unusual feature of the book is its unified treatment of reflection and transmission at interfaces which is presented in Chap. 7. Most of the subtopics here are to be found in standard texts with the exception of the solid-fluid interface which is covered in some detail, and provides a good prelude to the discussion of surface waves. The concept of slowness is introduced. Chapter 8 is devoted to surface (Rayleigh) waves. Rayleigh’s basic theory is reviewed, showing that waves can propagate with energy confined to a solid–vacuum interface. For a fluid-loaded surface there are various possibilities including a pure lossless mode, called a Stoneley Wave, and various “leaky” Rayleigh waves. The topic of displacement of beams of finite widths, when being reflected, is discussed. Other waves known as Schmidt head waves are summarized. Chapter 9 covers Lamb waves which propagate in plates. The same potential method is used as for reflection of bulk waves and Rayleigh waves, but in this case the presence of the second boundary leads to symmetric and antisymmetric solutions. Fluid-loading effects are discussed and then fluid-loaded cylinders with mention of creeping waves. In Chap. 10 Cheeke introduces partial wave analysis as a technique for analysis of acoustic waveguides which can be used more generally than the potential method. He starts with horizontal shear (SH) modes and rederives results for Lamb and Rayleigh waves. We then move on to layered substrates as a case first studied in seismology but also of interest in nondestructive evaluation (NDE) of multilayered electronics. Love waves are modified SH waves which propagate in a thin crust on a half-space. Conditions for trapping or leakage are examined. There are similar analyses for Lamb and Stoneley waves, there is a brief review of guided waves in multilayered structures. The cylinder as a waveguide is a classical problem which Cheeke simply summarizes. The chapter is concluded with a discussion of general considerations in the design of acoustic waveguides. Chapter 11 covers crystal acoustics. Cheeke derives the Christoffel equation which is the basis for finding the phase velocities of the three waves which can propagate in an anisotropic medium. The cubic crystal is taken as a specific example. The Poynting vector does not necessarily coincide with the phase velocity direction. The thermodynamic theory of piezoelectricity is also included in this chapter as also the concept of piezoelectricity coupling factor. This leads us on to Chap. 12 where we encounter piezoelectric transducers, delay lines, and analog signal processing. An equivalent circuit for a bulk acoustic wave (BAW) transducer was first proposed by Mason. The BAW and later the surface acoustic wave (SAW) transducer led to the development of the delay line which was of importance during World War II because the velocity of acoustic waves is $10^5$ times that of light so that the dimensions of the devices became practicable. SAW devices are compatible with microelectronic technology and have become the basis of a whole signal processing technology. The discussion here follows G. S. Kino’s “Acoustic Waves: Devices, Imaging, and Analog Signal Processing.” Chapter 13 is perhaps the most original in the book in that it contains more of Cheeke’s research interests on acoustic microsensors. He starts by describing the action of the thickness-shear mode (TSM) resonator whose resonance frequency is altered by an absorbed thin film. TSM resonators may be used in liquids. SAW sensors are very sensitive to surface environment changes and a number of examples are given. SH type sensors are described as also flexural plate wave (FPW) sensors and thin rod sensors. These devices can be used for gravimetric measurements of deposits, and density and viscosity of liquids. Other applications include temperature, flow, and level sensing. Chemical gas sensors detect, identify, and measure the concentration of chemical species in a gaseous environment. Gas chromatography with acoustic detection and biosensing are discussed. Chapter 14 covers acoustic microscopy. The scanning acoustic microscope (SAM) was developed by Lemons and Quate in 1973 and is now used in NDE of microelectronics and imaging of biological samples. The SAM does not have the problems of optical microscopes. Topics such as resolution, lens design, contrast mechanisms, and measurements are covered in some detail. Finally, details of some applications are given, including the imaging of biological samples, films and substrates, and NDE of materials and devices. The chapter finishes with an assessment of the subject in which Cheeke opines that the future lies with the application of atomic force microscopy to acoustic imaging. Chapter 15 is a review of NDE of materials covering some modern developments having application in microelectronics. The material here shows how the theory of Chaps. 7–9 can be applied in practice. The emphasis is on Rayleigh wave NDE, critical angle reflectivity, Lamb waves, and inversion techniques for layered structures, especially the modal frequency spacing method. There are sections on measurements of thickness, adhesion, and cladding. Chapter 16 comprises some special topics which Cheeke believes to be of future potential importance in ultrasonics. He starts with multiple scattering, a topic of concern in several areas, with emphasis on Biot’s theory of multiple scattering by solid particles in liquids. This is followed by a discussion of time reversal, a technique with the potential to improve signals received in situations with multiple scattering. Picosecond ultrasonics, or the use of extremely short pulses, generated by lasers, for example, is discussed as also air-coupled ultrasonics. The chapter concludes with a section on resonant ultrasonic spectroscopy, a variant of acoustic signature analysis. Chapter 17, which concludes the volume, is on cavitation and sonochemistry (SL). It begins with a review of bubble dynamics drawing on T. G. Leighton’s “The Acoustic Bubble.” The reader becomes acquainted with such concepts as cavitation threshold, cavitation noise, subharmonics, etc. Older work using sound fields containing many bubbles and the features of SL under such conditions is summarized. The opening up of the subject that occurred after the perfection of techniques for studying SL from single bubbles is then described. The interesting recent work which points to a dissociation mechanism as the explanation of SL is summarized well. However, practical applications of cavitation, such as cleaning and processing are not mentioned. The book would be suitable for physicists and mechanical and electrical engineers. Previous books on ultrasonics are not referred to, perhaps because they are heavily technological, although Cheeke stresses in the Preface that applications are to receive emphasis in the volume. In comparison with earlier books, the approach is quite mathematical and the work could in fact pass for a treatise on physical acoustics. Another similar indication is the omission of any discussion of systems theory and digital signal processing, on which some of the most important developments in medical ultrasonics and NDE depend. With these exceptions the book is a good addition to the ultrasonics literature in general and should be invaluable to workers in the NDE of microelectronics in particular.

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