Part III
Efficient Numerical Methods for Wave Propagation Analysis

Abstract Numerical models are a vital part of any endeavor to understand the physical behavior of systems that are not accessible for direct measurements or where measurements are very costly and time-consuming. One prime example is the simulation of ultrasonic guided waves in lightweight and thin-walled structures. From our point of view numerical tools are of utmost importance in the context of structural health monitoring (SHM). In order to design a robust and reliable SHM system, the physical mechanisms governing the wave propagation in such structures have to be understood in detail. The necessary knowledge can be acquired by employing advanced numerical simulation approaches to support experimental investigations. Therefore, the current part of the book is devoted to describing efficient numerical methods for wave propagation analysis. To this end, we introduce different computational approaches for studying the propagation of elastic waves. As mentioned before, our main focus lies on guided wave-based SHM applications. This is a very demanding field of research since the high-frequency regime in which we operate demands a rather fine spatial as well as temporal resolution of the structure under investigation. Additionally, different issues such as the computation of dispersion curves and the transient analysis of guided waves need to be tackled. In that regard, we have to bear in mind that not a single method is able to efficiently handle all problems arising when studying guided waves. Therefore, we discuss the advantages and disadvantages of various methods with respect to the intended area of application. By doing so, we hope that the reader gets a deeper understanding of two important issues:

1. Which methods are suitable for which problems?
2. Why are only certain methods applicable for particular tasks?

Important numerical methods that we want to introduce to the reader are:

1. The *p*-version of the Finite Element Method,
2. The Spectral Element Method,
3. The Isogeometric Analysis,
4. Analytical and Semi-Analytical Approaches,
   (a) Semi-Analytical Finite Element Method,
   (b) Hybrid Methods (coupling of numerical and analytical methods in the frequency domain),
5. Fictitious Domain Methods,
   (a) The Finite Cell Method,
   (b) The Spectral Cell Method.

Although a wide variety of other numerical approaches also exist, we limit ourselves to the ones listed above. We believe that these methods are appropriate to solve all problems related to wave propagation efficiently. Emerging methods are nonetheless briefly mentioned and we refer the reader to relevant literature.

The content of the current part is based on the investigations of seven young researchers who worked on a SHM-related project over the last 7 years. Therefore, we would like to acknowledge the contributions made by Z.A.B. Ahmad, J.M. Vivar-Perez, C. Willberg, S.M.H. Hosseini, S. Duczek, C. Heinze, and B. Hennings. Their scientific work is cited where it is appropriate to avoid unnecessary misunderstandings. The core of what is presented in the current part is compiled in their PhD theses [1–7].

During the course of the investigations concerning SHM and the numerical analysis of elastic guided waves in particular the authors wrote a comprehensive review article on computational methods for wave propagation analysis. This paper summarizes important advances in the topic and highlights the applicability of the individual approaches to different problems encountered in SHM applications. Therefore, we kindly refer the reader to this article when dealing with the simulation of guided waves [8].

References

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