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Title(English)	Fast time-domain boundary element method and its application to nonlinear ultrasonic simulation
著者(和文)	丸山泰蔵
Author(English)	Taizo Maruyama
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Category(English)	Doctoral Thesis
種別(和文)	論文要旨
Type(English)	Summary

（博士課程）
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論 文 要 旨

THESIS SUMMARY

専攻： Department of	情報環境学（社会・環境系）	専攻	申請学位（専攻分野）： Academic Degree Requested	博士 Doctor of	（ 工学 ）
学生氏名： Student's Name	丸山 泰蔵		指導教員（主）： Academic Advisor(main)	教授 廣瀬 壮一	
			指導教員（副）： Academic Advisor(sub)		

要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

In this dissertation, a convolution quadrature time-domain boundary element method (CQ-BEM) has been accelerated using a fast multipole method (FMM) and a rapid convolution algorithm for solving large-scale wave problems. The author has applied the proposed fast CQ-BEM to numerical simulations of nonlinear ultrasonic testing (NLUT) based on the contact acoustic nonlinearity (CAN). He also investigated causes and characteristics of the nonlinear phenomenon from obtained numerical results.

This dissertation is organized by the following seven chapters:

Chapter 1 [Introduction]

The previous studies on the NLUT based on CAN and time-domain BEM including the CQ-BEM were reviewed in Chapter 1. The author then mentioned the importance and requirement of theoretical approach to nonlinear ultrasonic phenomena. He also pointed out the limitations of conventional time-domain BEM for wave problems. The organization of this dissertation is also described in this chapter.

Chapter 2 [Convolution Quadrature Time-domain Boundary Element Method (CQ-BEM)]

Although the time-domain BEM is considered as the most appropriate numerical method for the nonlinear ultrasonic simulation, the conventional one in which a collocation method is used for time discretization has disadvantages in its numerical stability. Therefore, as the solution of this issue, the CQ-BEM based on implicit Runge-Kutta scheme (IRK-based CQ-BEM) has been proposed. Its important aspects were presented through numerical examples for three-dimensional (3-D) acoustic wave problems. Then, the author pointed out that the computational complexity of the IRK-based CQ-BEM is large, and application of acceleration techniques is often required.

Chapter 3 [Acceleration of CQ-BEM]

The IRK-based CQ-BEM has disadvantages in its computational cost, and the original computational and memory complexities are $O(N^2M^2)$, where N and M denote the numbers of time steps and elements, respectively. Therefore, the acceleration of CQ-BEM for 3-D acoustic and elastic wave problems using the FMM and rapid convolution algorithm have been presented in Chapter 3. As the result of acceleration, the computational and memory complexities could be reduced to $O(NM\log N\log M)$ and $O(NM)$, respectively. The accuracy and efficiency of fast CQ-BEM were also confirmed by solving wave problems numerically.

Chapter 4 [3-D Simulation of Higher-harmonic Waves Due to an Interface Crack]

From Chapter 4, the application of IRK-based CQ-BEM to nonlinear ultrasonic simulation has been discussed. The 3-D simulation of nonlinear ultrasonic waves due to an interface crack with contact boundary conditions between two semi-infinite elastic solids, has been performed in Chapter 4. This problem can be considered as the wave scattering by a nonlinear imperfection on a bi-material interface. The appropriate boundary element formulation for this problem has been proposed in order to accurately compute the

tangential velocity of displacement which is included in the nonlinear boundary conditions. The author carried out some numerical simulations of the higher-harmonic generation in NLUT and validated the numerical model of interface crack through obtained numerical results.

Chapter 5 [2-D Simulation of Nonlinear Ultrasonic Waves Due to Interior and Surface Breaking Cracks]

Some 3-D nonlinear ultrasonic simulations were performed in Chapter 4. Since the boundary element formulation was developed for an interface crack between two semi-infinite elastic solids, not only the boundary elements of interface crack but the ones of bi-material interface were also required. Thus, it is difficult to conduct long-time analyses and to confirm the sub-harmonic generation using the method owing to its computational cost. In Chapter 5, therefore, 2-D long-time analyses of nonlinear ultrasonic generation by interior and surface breaking cracks have been implemented by the non-accelerated CQ-BEM. Complex shape and arrangement of cracks were considered because the multiple reflection of bulk waves is significant to the sub-harmonic generation in view of the previous researches. Moreover, the nearly stationary vibration fields must be investigated to confirm the sub-harmonic generation.

From numerical results, the author succeeded in the numerical simulation of sub-harmonic generation and investigated the relationship between the nonlinear sub-harmonic resonance and frequency response characteristic of the linear system. It was also found that the behavior of sub-harmonic generation due to a surface breaking crack is different from that due to interior cracks.

Chapter 6 [3-D Simulation of Nonlinear Ultrasonic Waves Due to Interior Cracks]

The 3-D simulation of nonlinear ultrasonic waves due to interior cracks has been conducted by the fast CQ-BEM, which is presented in Chapter 3, in order to investigate dimensional effects in the sub-harmonic generation. In practice, the shape and arrangement of cracks have 3-D geometry, and it is important to evaluate the dimensional effect. Therefore, the numerical method that was developed in Chapter 5, has been extended to the 3-D crack problem.

From numerical results, it was confirmed that the sub-harmonic generation is caused under the similar conditions to the 2-D cases. However, the dimensional effect is significant to the characteristic of sub-harmonic generation, and it was hard to observe the sub-harmonic generation compared with the 2-D case.

Chapter 7 [Final Remarks]

The author stated the conclusions of this dissertation and mentioned the future prospects.