TOPOLOGY OPTIMIZATIONS OF SOLIDS AND FLOW CHANNELS BASED ON LEVEL SET METHOD USING BOUNDARY ELEMENT METHOD AND LATTICE BOLTZMANN METHOD

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ABSTRACT

This keynote lecture presents some application of boundary element method (BEM) and lattice Boltzmann method (LBM) to topology optimization problems in heat conduction, acoustic, elastodynamic, electromagnetic, and flow problems. Topology optimization is a structural design method to obtain the optimum shape allowing its topological change. The optimum shape can be considered as the optimum distribution of material, therefore, numerous works have treated topology optimization problems as the optimum material arrangement problems. However, the conventional works assume the existence of materials with small material constant values also in the area where the material should not exist, and the resulting material configuration is in fact different from the optimum one. Also, it is difficult to give explicit boundary conditions to the newly generated boundary of the material. Therefore, our laboratory employs a level-set based approach with which the boundary of the material is explicitly generated from the isosurface of the level set function. In the first part of this lecture, numerical scheme of topology optimization based on the level set method and BEM is presented. This approach has been applied to topology optimization of sound scatterer designs in acoustic problems. Sound pressure is measured at some points in a three-dimensional acoustic field and the optimum layout of the sound scatterers has been obtained so that the sum of the sound pressure levels at the measuring points is minimized. Another example of BEM application has been done for the topology optimization of the arrangement of dielectrics for cloaking of objects. The layout of the dielectrics with which the scattered waves were finally reconstructed to become the same incident plane wave in order to cloak the object. It turned out that, by defining the objective functional appropriately, objects of any shapes and material properties can be cloaked by using the same layout of the dielectrics.

In the second part, I will show some topological designs of flow channels. For such problems, it is crucial to employ a fast flow solver because we have to repeat flow analysis many times until we obtain the optimum topology of the channel. The LBM and its variant, lattice kinetic scheme (LKS), have been used for solving primary problem and newly derived adjoint lattice Boltzmann equation. LBM and LKS are rather fast because they are explicit methods for calculating the values of the velocity distribution function in the fixed design domain. The flow velocity, pressure, density, and internal energy are calculated from this distribution function directly. Memory requirement in LBM is heavy but is improved dramatically in LKS. The level set method was used again to control the boundary of the flow channel. This computation scheme was applied successfully to designs of flow channels to minimize the pressure drop between the inlet and outlet flows. The method was also applied to maximization of the dissipation energy of the fluid in the channel under transient but time harmonic inlet and outlet flows to design vibration damping devices based on fluid mechanism.

Keywords: Topology optimization, Level set method, Boundary element method, Lattice Boltzmann method

Biographical Sketch

Professor Toshiro Matsumoto is a professor of Nagoya University since 2004 and has a laboratory in the Department of Mechanical Systems Engineering. He has dedicated his study to boundary element methods (BEM) and its application to engineering problems. His contributions have been in the application of the boundary element method to fracture mechanics, development of BEM for inhomogeneous material, shape sensitivity analysis, BEM for piezoelectric materials, and application of BEM to topology optimizations. In recent years he is also interested in topology optimization related to flow problems using lattice Boltzmann method. He has published more than 200 journal papers and also more than 200 presentations in international conferences. He wrote two books on BEM and chapters of 7 books.

He is an editor of Engineering Analysis with Boundary Elements, former director of the Japan Society of Mechanical Engineers (JSME), Vice Chairman of the Computational Mechanics Division of JSME, Fellow of JSME, and Director of Japan Society for Computational Methods in Engineering (JASCOME). He has been a visiting professor at Wessex Institute, University of Pisa, École Polytechnique, and London University. He taught in China and Italy on BEM and topology optimization. He and his research group won many awards from JSME and JASCOME. He is nominated as the next president of JASCOME.