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Determination of optimum design spaces for topology optimization

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Abstract

Due to tolerances allowed in deciding the design space in preliminary designs, two approaches are proposed to find the optimum design space systematically. One is to use Taguchi orthogonal array to do experiments for some design spaces and find optimum topologies in these design spaces. The results of the experiments are used to determine the optimum boundaries of the design space. The other approach is to use genetic algorithms (GA) to search for the optimum boundaries of the design space. To reduce the computational burden of GA, the artificial neural network (ANN) is used to replace the time-consuming processes of finding optimum topologies in all individuals (design spaces) of a generation. The GA search is thus accelerated. Two examples are used to demonstrate and test the approaches. Based on numerical results the methods are reliable, practical, and efficient. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Optimum design space; Topology optimization

1. Introduction

Since Bendøse and Kikuchi's paper [1] was published in 1988, the research of structural optimization has entered a new era of topology optimization. A lot of papers in this research area have been presented [1–15]. Most papers dealt with minimum compliance design subjected to the constraint of certain material allowed in the design space. Some other papers discussed the designs for maximum eigenvalue or minimum frequency responses. The optimum solutions formed the topologies of the structures. In solving the topology optimization problems, two major approaches were used. One was the homogenization method introduced by Bendøse and Kikuchi [1]. The

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other one was the density method suggested by Mlejnek [2]. In using homogenization method three design variables were associated with each finite element. Two of them represented the dimensions of the rectangular hole in the element and the last one was for the orientation of the hole. The element was considered to be anisotropic due to the hole. The Young's moduli for some specific design variables were calculated by homogenization. Interpolations were then used to predict other Young's moduli in the design domain. The density method assumes the material to be isotropic and each design variable varies between 0 and 1. A nonlinear function which gave penalty to the intermediate design variables was used to get the Young's modulus for each finite element. Although the theoretical basis is weaker for the density method, the computational efficiency is higher. Genetic algorithm and other methods have also been tried to solve the topology optimization problems. Duda and Jakiela [13] used GA-based sharing functions and restricted mating to find various topologies in the design space. Chu et al. [14] computed the sensitivity number for each finite element and this number was an indicator to determine whether the corresponding element should be removed. Chen [15] used simulated self-organizational bone remodeling method to solve the topology optimization problems. The simulation of resorption and formation of bone tissue was employed to form the topology.

To improve the solutions of topology optimization, Diaz and Sigmund [12] proved that using higher-order elements could avoid the formation of checkerboard patterns. Haber et al. [11] proposed to add penalties to the intermediate design variables as well as to impose perimeter constraint in order to generate a practically usable topology. Maute and Ramm [10] used adaptive design space which was approximated by cubic or Bezier splines and therefore produced a smooth configuration. In recent years the topology optimization has been applied to industrial uses. Yang and Chahande [8] designed optimum automotive frame. Yang and Chuang [3] used topology optimization in designing engine mount bracket. Hajela and Lee [7] designed rotorcraft subfloor structures for crashworthiness considerations. Ou and Kikuchi [6] integrated topology optimization with vibration control. Jiang and Chirehdast [5] designed optimal connections using topology optimization.

For all these previous researches the topologies were formed within a specified design space. If the design space changes, the topology will change as well. In many design applications some of the design spaces are roughly given by the designer in the preliminary design stage. That is, there are tolerances for the boundaries of the design space. To take advantage of these tolerances on the design space boundaries, the best topology can be generated in the optimum design space boundaries. It is therefore the purpose of this paper to find the optimum design space boundaries and the optimum topology in this design space. Taguchi method and the genetic algorithms are two approaches used in this paper to determine the optimum design space boundaries. To reduce the computational cost associated with GA, the artificial neural network is employed to replace structural analyses and designs. Two numerical examples will be given to demonstrate the idea. The results are satisfactory.

2. Taguchi method

Taguchi method [16,17] was first introduced in 1980s. This method was originally used for quality control and process improvements and has been successfully used in various fields.