ABSTRACT

Topology Optimization for High-Cycle Fatigue under Random Loading

Youngwoo Jo

(Directed by Professor Seungjae Min, Ph. D.)

Department of Automotive Engineering

Graduate School

Hanyang University

Recently, efforts have been made to reduce the weight of parts and meet the tightened fuel economy regulations in the automotive industry, and design optimization for lightweight have been developed to satisfy the performance required for machines and structures. The topology optimization method is mainly applied to the conceptual design and enables us to derive the optimal design without depending on existing designs and to propose the innovative designs. However, although many studies have been conducted on topology optimization methods considering structures' global properties such as compliance and natural frequency, studies on topology optimization methods considering the physical quantities sensitive to local changes in structural shape such as stress and fatigue are at an early stage.

In order to implement the lightweight topology optimization design considering high-cycle fatigue, this thesis proposed two constraints. The first was critical fatigue stress under fatigue loading, and the second was fatigue damage. Critical fatigue stress is the reference value to determine the occurrence of fatigue failure and used to determine the fatigue failure by comparing the stress values when unit load was applied to the structure. Critical fatigue stress is determined by fatigue analysis before the optimal design process and the optimal design is obtained without fatigue failure by acting as a constraint of stress based topology optimization. Fatigue analysis is not performed any more in the process of the optimal design. Therefore, it has the advantage of having smaller amount of calculation than that of the fatigue damage based topology optimization. However, although it is possible to design lightweight structures without fatigue failure, there are limitations to the use of the design sensitivity reflecting the properties of the stress.

The fatigue damage constrained topology optimization design is a method to directly calculate the design sensitivity to fatigue damage and then perform the optimization using this. Therefore, fatigue analysis and design sensitivity calculation should be performed every iteration in the optimal design process. It is difficult to calculate design sensitivity because non-differentiable operations are used in the process of calculating the fatigue strength based on the fatigue failure theory. In order to solve this problem, the fatigue failure theory was calculated by approximating differentiable operations. Even though fatigue damage based topology optimization has the disadvantage of requiring more calculations than the topology optimization for critical fatigue stress constraint and performing the optimal design in consideration of the fatigue damage with more nonlinear characteristics than stress, it has the advantage of produce a optimal design by performing optimization reflecting fatigue properties because the sensitivity to the fatigue damage.

In order to verify the applicability of the two proposed methods, density based topology optimization scheme is employed to cantilever and MBB beam design for lightweight structures without fatigue failure concerning different types of fatigue loading. After the comparison of results, level set based topology optimization scheme is implemented for only fatigue damage constraint.