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Integrated Structural Optimization with T-Spline Finite Element Method (TSFEM)

***Yu-Deok Seo[1] and Sung-Kie Youn[2]**

[1] Department of Mechanical Engineering, Korea Advanced Institute of Science and Technology
373-1, Guseong-dong, Yuseong-gu, Daejeon, Republic of Korea, 305-701
imop@kaist.ac.kr

[2] Department of Mechanical Engineering, Korea Advanced Institute of Science and Technology
373-1, Guseong-dong, Yuseong-gu, Daejeon, Republic of Korea, 305-701
skyoun@kaist.ac.kr

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ABSTRACT

In this present work, integrated structural optimization approach with T-spline finite element method (TSFEM) is presented for fully unified framework on CAD/CAE including modelling, analysis and design optimization.

In conventional shape optimization, boundaries are represented by spline and control points are employed as design variables. FEM or BEM is used for numerical analysis. In order to define relation between control points and finite element model, parameterization of design variables with finite element model is required. Main limitation of shape optimization is that topological changes are not possible and time consuming remeshing task is required during optimization process. In topology optimization, flexible topological changes are possible. However its result is generally restricted on the initial computational mesh. Moreover, for communication with CAD systems, post-processing procedure should be done. Although many studies and attempts to integrate shape and topology optimization were done, their works also suffer from troublesome remeshing, parameterization and restriction of design space.

In several works, splines were employed in finite element analysis to reduce numerical error which comes from finite element approximation of geometries[1-3]. Recently, a locally refineable and efficient T-spline finite element method was proposed[4,5]. In these approaches, field variables as well as geometries are represented by spline basis function. Therefore, the overall analysis process including modeling and analysis can be performed by spline with efficiency and accuracy. TSFEM is also promising approach in design optimization because modeling, analysis and optimization can be integrated by the same spline data. Therefore design results are directly communicated with CAD system without additional post-processing process. Moreover, global optimum solution can be obtained in natural way since spline is not restricted on the initial design domain.

Compliance minimization of cantilever beam with volume constraint is dealt with as a benchmarking problem. Figure 1 shows design object and its finite element model. Filled circles are control points. In two-dimensional problem, control points which represent boundaries are chosen as design variables. Additional two control points are inserted on the boundary, where essential boundary condition applied, by T-spline local refinement with knot multiplicity to guarantee reasonable area of restraint. Optimization problem is formulated as follow:

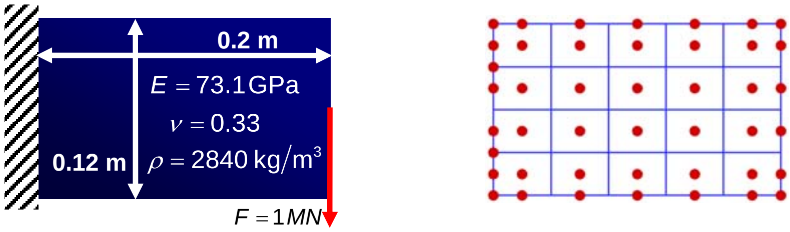

Fig. 1. Cantilever beam: geometry, its FE model and distribution of control points

$$
\begin{aligned}
&\text{Minimize} && \Psi = \mathbf{F}^T\mathbf{u} \\
&\text{Subject to} && V/V_0 = 0.7 \\
& && x^i_{\min} \le x^i \le x^i_{\max} \qquad i = 1,\cdots,NDV
\end{aligned}
$$

Side constraints of design variables are determined based on the minimum distance between design variables and other control points. Sensitivity analysis is performed in discrete sense and MMA(Method of Moving Asymptotes) is employed for optimizer. Figure 2 shows optimal result and its iteration history. Design space is naturally expanded and two bar structure which is global optimum of cantilever beam problem is obtained by proposed approach.

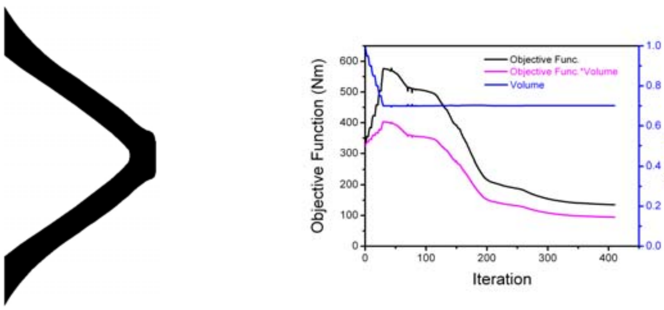

Fig. 2. Optimum solution and iteration history

As further works, an efficient scheme for topological change in a single spline surface will be proposed based on the topological derivative and its validity will be verified.

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