Topological Optimization using Guide Weight Method

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Abstract

Topology optimization has become a very active area of research and various methods have been proposed to deal with topological optimization problems. Generally, the topology optimization deals with finding the optimal material distribution in a design domain while minimizing the compliance of the structure. In this work, focus has been kept on a topology optimization of a rotating disc having four point loads.

Keywords — *Guide Weight (GW) method, OC method, topology optimization, Q4 element, compliance, tangential and centrifugal forces*

I. INTRODUCTION

Due to increased competition, the ever increasing demand to lower the production costs has prompted engineers to look for rigorous methods of decision making such as optimization. Engineering optimization was developed to help engineers design systems that are both less expensive and more efficient and to develop inventive methods to improve the performance of the existing systems. Having reached a degree of maturity over the past several decades, optimization techniques are currently being used in a wide variety of industries, including automotive, MEMS, chemical, electrical manufacturing industries and aerospace. Optimization methods coupled with modern tools of computer-aided design are being used to enhance the creative process of conceptual and detailed design of engineering systems. A number of optimization techniques have been developed for solving two different types of optimization problems because there is no single method or technique for solving efficiently all optimization problems. It depends on the engineer to choose a technique which is computationally efficient, accurate and appropriate for his design problem.

Topology optimization changes the neighbourhood relations of the topological domain and transforms the existing topology into improved topology, i.e. improves transformations into other topology classes and modifies the interrelations between the constitutive elements of a design domain. Topology optimization is roughly divided into two types of problems such as topology optimization for discrete structures and continuum structures. The research work on topology optimization for discrete structures has a much longer history than that for continuum structures ever since the initiating work over a century ago by Maxwell (1890) and Michell (1904) that concerned the layout optimization theory for thin bar structures such as truss. Therefore it is inherently recognized that layout optimization deals with discrete structural optimization and is also called truss topology optimization. On the other hand topology optimization for continuum structures considers the structures to have large volume fraction that means structural material occupies a large portion of the available space. Rozvany *et al*. (1991) introduced the term generalized shape optimization and Haber *et al.* (1994) [12] introduced the term variable topology shape optimization for this type of topology optimization. These two types of topology optimization for discrete structures and continuum structures both involve the selection of the optimal topology. The basic meaning of topology optimization implies improving the structural topology.

In 2005, Bruneel and Duysinx [10] investigated topology optimization problems including self-weight. They pointed out that there are three particular difficulties in solving this type of problem, namely, inactive volume constraint of the optimal topology, non-monotonous behaviour of the compliance and parasitic effect for low density regions when using the SIMP method. After this, they proposed a modified discontinuous SIMP model and a new solution method combining the Method of Moving Asymptotes with the Gradient Based MMA to deal with these difficulties, but the results of their solutions are not very ideal in terms of the figure legibility and solution efficiency. Following the study of Bruyneel and Duysinx, various researchers have focused on this area. Ansola et al. (2007) [7] proposed a modified sensitivity computation strategy for the ESO method to deal with this problem and they obtained convenient results, but their method lacks theoretical basis. After this Huang and Xie (2010) [12] developed a new BESO method utilizing the RAMP model to optimize structures with self-weights and demonstrated its capability to generate convergent optimal solutions with numbers of examples. Many works have been conducted but the efficiency of solving such kinds of topology optimization problems has not been improved so much. One main reason is that all these works mentioned above solve this problem either by utilizing the MP methods or the heuristic methods, which all share the same shortcoming of low computational efficiency.

The non-monotonous character of this kind of problem may be more easily to be solved with the OC method. Considering both the limitation of MP methods and heuristic methods and the unique advantage of OC methods, in this work an OC method (Guide-Weight method) is used into continuum structures optimization under body forces. The Guide-Weight method was first proposed by Chen in the 1980s for the optimization of large-scale antenna structures. In 2013 H. Xu, *et al.* introduced the GW method for for topology optimization of continuum structures including body forces.
In this work MATLAB code is generated using Guide Weight Algorithm (given by H. Xu, *et al. [2013]*) for a disc having four point loads and results of this MATLAB code is validated by ANSYS.

II. PROBLEM FORMULATION

The topological optimization problem of continuum structures aimed at minimized mean compliance and subjected to a mass constraint can be usually expressed as follows:

Find: $\rho = [\rho_1, \rho_2, \ldots\ldots \rho_n]^T \in R^N$

Min: $C(\rho)$

Subjected to: $v(\rho) \leq f\, v_0$

(3.14)

$0 < \rho_{min} \leq \rho_i \leq 1$

$i = 1, 2, \ldots\ldots\ldots\ldots N$

Where ρ_i is the relative density of the i[th] element, ρ_{min} is the minimum value of the design variables, N is the quantity of the elements, $C(\rho)$ is the mean compliance, and M and M_0 are the expected weight and initial weight of the design domain, respectively.

III. ASSUMPTIONS AND MODEL GEOMETRY

Centrifugal force is another typical body forces that commonly exists in many rotating engineering structures, such as human centrifuges, rotating platforms etc. In this work, the topological optimization of the disc has been done that withstands both tangential and centrifugal forces.

Figure (1) illustrate a disc-like design domain, whose inner and outer radii are 5 cm and 30 cm, respectively and having four point tangential load of 250 N. The following material properties are assumed: Young's modulus (E = 200 GPa) and Poisson's ratio ($\upsilon = 0.3$). The penalty factor p is set to be 3.

The body force in this case is the centrifugal force caused by ω. The load direction vectors of elements vary with their positions. When the centrifugal force is not taken into account, the amplitude of F has no effect on the ultimate topology. The topology in this situation is presented in figure (3).

If both tangential and centrifugal forces are considered, we obtain the optimal topology as illustrated in figure (5). A clear distinction between these two load conditions is observed, and the optimal structure in the second situation has directional deflection along with ω, which makes sense from an engineering perspective. Figure 2 shows the meshing of the disc.

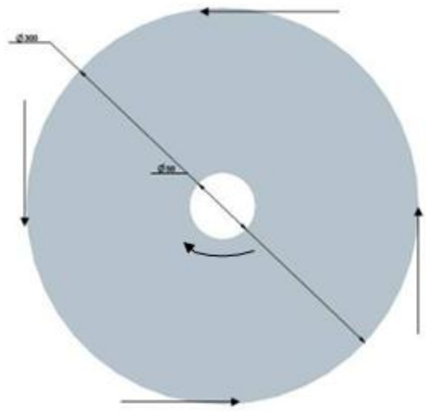

Fig. 1 Rotating Disc Having Four Point Tangential Load Of 250 N

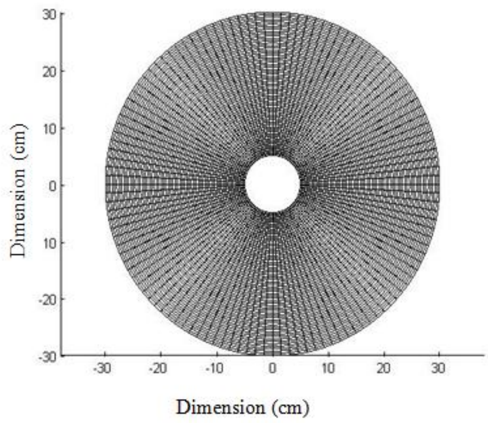

Fig. 2 Meshing of the Disc Using Q4 Element and Number of Element in Radial and Circumferential Direction are 61 and 121 Respectively

A. Topological Optimization of Disc with Four-Point tangential forces and centrifugal forces

Disc with four-point fixed load has been optimized by GW Method using MATLAB code. The structure is discretized in number of small finite elements using Q4 element. In GW method the density of the element changes after every iteration and material is removed from the nodal points where stress intensity is minimum keeping the structure stable. In the beginning the compliance of this disc was 39.27 N-cm and 250 N of fixed loads are applied on four points. After 35th iterations the compliance comes out to be 79.22 N-cm. The optimal shape of the Disc will be as following:

1) Final topological layout and stress distribution of the disc with four point loads not considering centrifugal forces has been shown in Figure 3. Here void region shows that the material has been removed from that region and material layout implies where material is present. The contour plot shows the variation of stresses in the disc and red and blue colour region show the maximum and minimum stresses at that point. As seen from the figure maximum stresses occur at the four points of application of forces and circumferentially near the centre. Also the stresses are symmetric about both horizontal as well as vertical planes passing through the centre. The optimized shape is also symmetrical about these two planes.

Comparing the results of four-point force considering only tangential force obtained by MATLAB code and ANSYS (figure 5), it is inferred that the topology figure obtained from GW method is similar to topology obtained from ANSYS. From these results it is concluded that GW method is more appropriated to solve topological optimization problems for its excellent merits of both efficient and effective.

2) Final topological layout and stress distribution of the disc, rotating in clockwise direction with four point loads considering both tangential and centrifugal forces is shown in Figure 5. The contour plot shows the variation of stresses in the disc. Here red colour region and blue colour region show maximum tensile stresses and maximum compressive stresses respectively.

Figures (6) and (7) show the plot of compliance and volume fraction with iteration respectively. The compliance increases with number of iterations and become constant after 35 iterations. After 35th iteration remaining volume of the disk is 22% and time taken in 35th iteration is 4.44 hours.

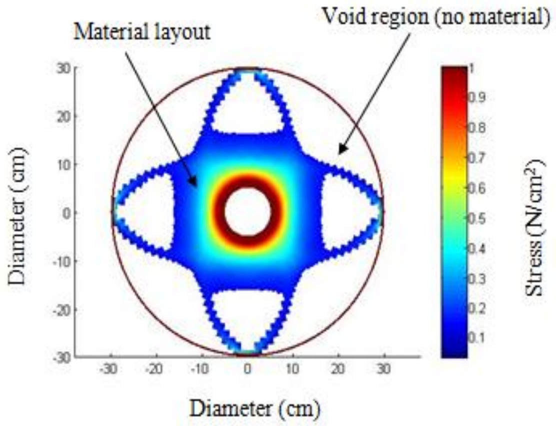

Fig. 3 Final Topological Layout and Stress Distribution of Disc Having Four-Point Load using GW Method

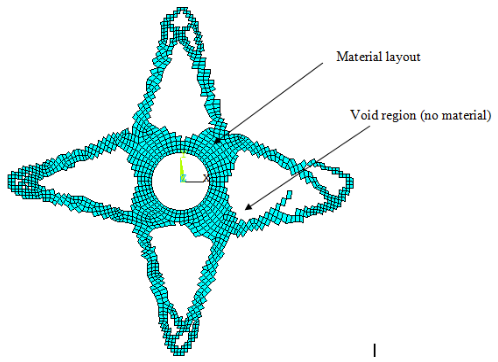

Fig. 4 Final Topological Layout of Disc Having Four-Point Load Using ANSYS

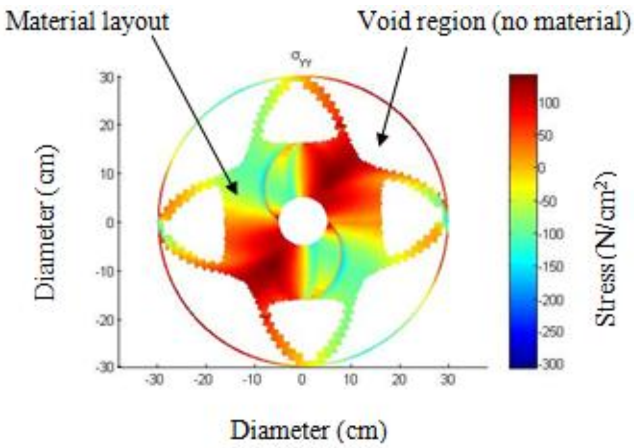

Fig. 5 Final Topological Layout and Stress Distribution of the Rotating Disc Having Four-Point Load and Considering Both Tangential and Centrifugal Forces

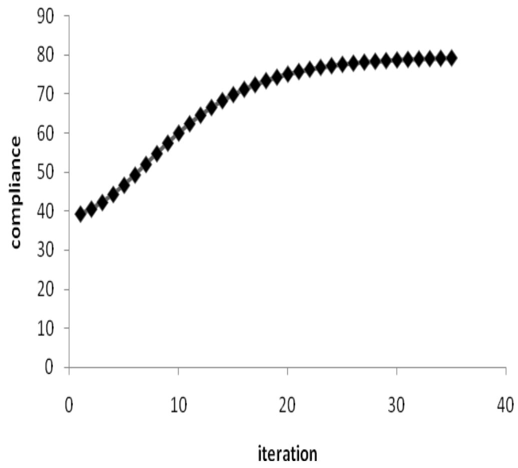

Fig. 6 Variation of Compliance for Four Point Loads using GW Method

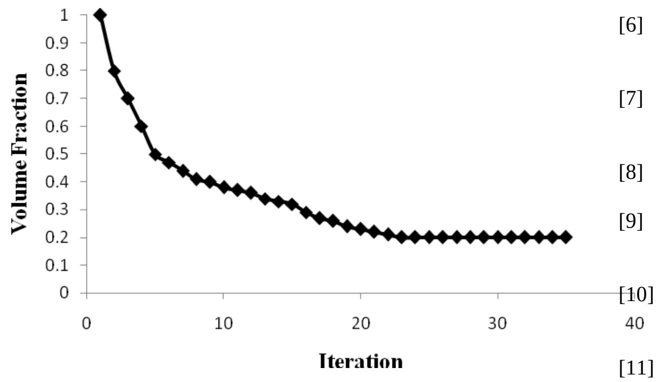

Fig. 7 Variation of Volume Fraction for Four-Point Load Using GW Method

IV. SUMMARY AND CONCLUSIONS

In this present work, an Optimality Criteria method for topology optimization of continuum structures under fixed force, i.e. the Guide-Weight method has been introduced to solve the topological problems withstanding body forces. The Guide Weight algorithm is used to develop a MATLAB code for finite element analysis of the continuum structure. Q4 element type is used for meshing the structure because of its high accuracy and flexibility in modelling complex geometry such as curved boundaries etc. Then topology optimization has been carried out for a disc having both tangential and centrifugal forces. The results demonstrate that the GW method is not only effective but also efficient in solving this type of problems. The main reason for the high computational superiority of the GW method is that this algorithm attributes to a kind of optimality criteria method known for its high efficiency.

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