A Methodology for Topology Optimization Using ON/OFF Method and its Application to Magnetic Actuator Designs

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The topology optimization of electromagnetic devices is a new emerging technique, and very attractive for a designer since an initial optimal design can be obtained beforehand. In this paper, a methodology using ON/OFF method is introduced to obtain the optimal topology of a magnetic actuator for maximizing the force in a specific direction. The methodology introduces an annealing mechanism for refinement and efficient topology optimizations. Using finite element method, the magnetic field is computed and the magnetic force is derived. To implement the ON/OFF method, the sensitivity of the objective function is computed according to the magnetic permeability perturbation on each element in the design domain. As a result, the optimal topology of the design domain is obtained and a significant improvement in performances is observed.

***Index Terms*—Magnetic actuator, ON/OFF method, topology optimization.**

I. Introduction

THE TOPOLOGY optimization of continuous structures has become a topical issue and it has made progress significantly in engineering optimization studies [1]. The topology optimization studies in computational electromagnetics are motivated by the works of fellow researchers in the structural design optimizations [2]. It is demonstrated that an optimal topology design that could not be imagined beforehand can be obtained. As a result, the topology optimization technique is very attractive for an engineer to start an initial design of an electromagnetic device.

In the conventional density method, the material density is set as the design variable, which changes continuously from zero to one. As a result, some gray scale elements occur in the final optimal topology obtained by using this method. On the other hand, ON/OFF method is a simple and efficient approach with an excellent convergent performance, especially for topology optimal problems having a good number of variables. Based on this, it has been successfully applied in the topology optimization of a magnetic recording heading, a magnetic shield, and a linear motor [3]-[5].

Magnetic actuators are widely used in electro-mechanical industries. Therefore, it is of great importance to improve the performance of a magnetic actuator. In this regard, the topology optimization is a promising technique to maximize the magnetic force in a specific direction under the condition of a limited input power. In this study, ON/OFF method is adopted to obtain the optimal topology of a prototype magnetic actuator. The magnetic field is analyzed by using finite element method (FEM) and the ON/OFF of the magnetic material in the design domain is pursued using the sensitivity information. The performance of the optimized topology is verified by comparisons with that of the original prototype.

II. Methodology of Topology Optimization

A. ON/OFF Method

In the ON/OFF method, the region (design domain) of the topology needing to be optimized is subdivided into different elements, as shown in Fig. 1. The material attribute of an element is updated iteratively in order to find a promising topology in terms of a performance parameter Q. Each element has only one state, void or solid. In Fig. 1, a gray cell is identified as a solid (the state is called "ON"), and a white cell is a void (the state is called "OFF") [4].

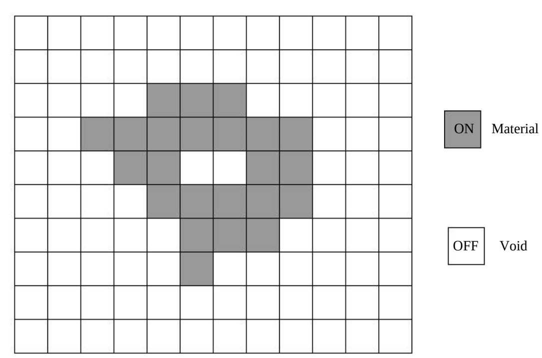

Fig. 1. ON/OFF method.

To determine the material attribute (ON/OFF state) of an element, the sensitivity, *dQ/dp* (*p* is the design variable, and is the magnetic permeability of the element in this case study) is used. If the sensitivity is negative, the cell is a void (air). If the sensitivity is positive, the cell is solid (magnetic material). The sensitivity of the i^{th} element is computed using a finite-difference approach as

$$\frac{dQ}{d\mu_i} = \frac{\left|Q(\mu_1, \mu_2, ..., \mu_i', ..., \mu_N)\right| - \left|Q(\mu_1, \mu_2, ..., \mu_i, ..., \mu_N)\right|}{\Delta\mu} \quad (1)$$

where μ_i is the permeability of the i^{th} element, $\Delta\mu$ is the perturbation of μ, N is the number of total elements in the design domain.

B. Topology Optimization Methodology

To facilitate the description of the proposed topology optimization methodology, its flow chart is given in Fig. 2. The methodology starts from an initial phase. In this phase, the initial topology, the mesh, and algorithm parameters are defined. After the initialization, the algorithm is transformed to compute the performance parameter using FEM and calculate sensitivity of each element using (1). According to these sensitivities, the attribute of every element is updated using the following rules: If the sensitivity of an element is negative, the permeability in the element *i* will be decreased, and the material will be set as air; Otherwise, the permeability in the element should be increased, and the element material is set as magnetic material. After the updating of element materials, the performance parameter for the new topology is computed.

To compute the sensitivity of each element, two virtual materials are introduced. The permeability of virtual materials is between the air and the magnetic material.

In the proposed methodology, an annealing mechanism is proposed for refinement and efficient topology optimizations. For this purpose, one introduces a successful updating as: if the performance parameter of the new topology is better than the current one, this updating of the new topology is called a successful updating. The algorithm will start an annealing process once the number of consecutive updating without any successful one reaches a predefined value. In the annealing process, the number of changeable elements, N_m, is decreased using the following equation

$$N_m = \gamma \cdot N_m \tag{2}$$

where γ is an annealing parameter, which is set as 0.85.

A promising byproduct of the annealing process is that a simple stop criterion can be designed as: if the changeable number N_m of elements in design domain is less than 1, the optimal procedures will be terminated. Nevertheless, the details about the annealing process will be given in details in the full paper for space limitations.

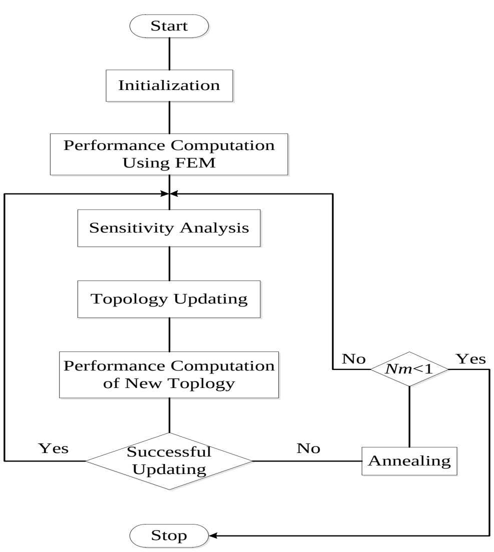

Fig. 2. Flow chart of the proposed topology optimization methodology.

III. Numerical Examples

The topology of a magnetic coupler is optimized to maximize the force in a specific direction. The details of the problem are referred to [6]. The design goal is to find the optimal shape of the core to maximize the driving force in the *x*-direction.

In the numerical implementation, the electromagnetic field is computed using FEM, and the actuating force is determined using a virtual magnetic energy method from the finite element solution using

$$F = -\frac{\partial W_{magnetic}}{\partial x} \tag{3}$$

The optimized topology of this case study using the proposed methodology is depicted in Fig. 3. The actuating forces for the initial and optimized topologies are, respectively, 42.67 and 52.90 (N/m), while the cross core area for the optimized topology is only about 92% of that of the latter.

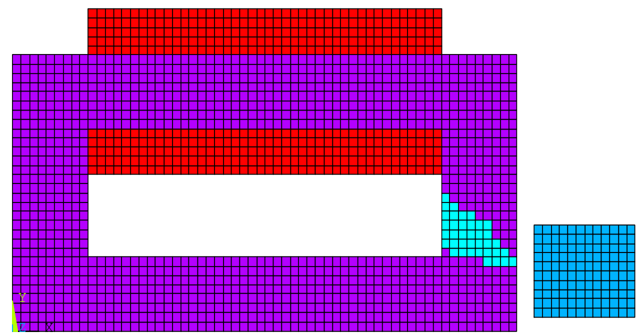

Fig. 3. The optimized topology of the case study.

IV. Conclusions

In this paper, a methodology based on ON/OFF method for topology optimization is proposed and applied to the topology optimization of a magnetic actuator. From the numerical results, it is worthy to notice that the actuating force of the armature is increased while the consumed material of the core is reduced. As a result, the topology optimization is a promising technique to enhance the performance of an electromagnetic device.

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