Dot Sensitivity Analysis of Ferromagnetic Material for Initial-Design-Free Topology Optimization in Magnetostatic System

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The hole sensitivity analysis was recently developed to solve the problem of topology simplification with design optimization process. However, the hole sensitivity analysis may fall into a local optimum because it cannot generate new design material in a vacant region, and an initial topology of design material should be given by designer. This paper presents a novel topology optimization method of dot sensitivity analysis to solve the above mentioned problems. The dot sensitivity is derived in an analytic form by using continuum shape sensitivity, and the adaptive level set technique is described for its numerical technique. Finally, the obtained dot sensitivity and the level set method are applied to two design problems to show its usefulness.

***Index Terms*—Dot sensitivity, Free initial design, Topology optimization, Adaptive level set method, Magnetostatic system**

I. Introduction

THE OPTIMAL DESIGN OF, electromagnetic system has received much attention for a long time due to its usefulness for optimization of device performance. The optimal design of electromagnetic system is to improve the device performance by optimizing sizes or shapes of given systems. Therefore, it can be widely used to design problems and can provide with important economic benefits. However, the optimal design of electromagnetic system has been limited in its application on account of difficulties such as excessive computation time, local minimum convergence, and complex expression of shape change. The shape optimization especially has been thought to be a very difficult problem because of its numerous design variables.

One way to solve this problem is to employ the topology optimization which combine the shape sensitivity analysis with the level set method [1-3]. By using this approach many good results was presented. In this method, an initial design of arbitrary given topology can be freely changed to converge to a final design with desired shape or topology. In addition, the hole sensitivity analysis was successfully developed to solve the problem of topology simplification, which frequently occurs in the topology optimization [4]. However, the hole sensitivity analysis has also two drawbacks. One is that an initial topology of design material should be given by designer. The other is that it may fall into a local minimum because it cannot generate new design material in a vacant region.

This paper presents a novel topology optimization method of dot sensitivity analysis to solve the above mentioned two problems. The dot sensitivity is the contrary concept of the hole sensitivity. The hole generation is to bore a small hole in a material region, by contrast the dot generation is to place a small dot of material in a vacant region. This paper derives the analytic form of dot sensitivity using the continuum shape sensitivity formula, and describes the adaptive level set technique for its numerical implementation. Finally, the obtained dot sensitivity and the level set method are applied to two design problems to show its usefulness.

II. Shape and Dot Sensitivity of Magnetostatic Systems

A. Continuum Shape Sensitivity

The design sensitivity of an objective function is analytically derived using the total derivative and the adjoint variable method. In magnetostatic systems, the continuum shape sensitivity is represented as [5]

$$\dot{F} = \int_\gamma G(A_z,\lambda)V_n d\,\Gamma = \int_\gamma \left(\frac{1}{\mu_2}-\frac{1}{\mu_1}\right)\vec{B}(A_z^{\;*})\cdot\vec{B}(\lambda^{**})V_n d\,\Gamma \tag{1}$$

where γ is the surface where the design variable is defined and V_n, which contributes to a shape variation, is the normal component of the velocity vector. The velocity field V_n is selected as

$$V_n = kG(A_z,\lambda) \tag{2}$$

where k is the scaling factor. The sign of k depends on whether the objective function should be increased or decreased. Its magnitude is selected to ensure that the variation of the design variable is suitable to the dimensions of the system.

B. Dot Sensitivity

The dot sensitivity is analytically derived using the continuum shape sensitivity with virtual hole concept. The dot sensitivity is defined as the variation of the objective function before and after generating the dot when a dot is sufficiently small. The dot sensitivity is defined as [4]

$$S(x) = \lim_{r\to 0}\frac{F(x,r)-F(x,0)}{A_{hole}}. \tag{3}$$

In magnetostatic systems, dot sensitivity is written as

$$S(x) = \frac{2}{\mu_1}\frac{\mu_2-\mu_1}{\mu_2+\mu_1}\vec{B}(A_z)\cdot\vec{B}(\lambda). \tag{4}$$

III. Numerical Examples

In this paper, topology optimization with free-initial-design is applied to practical design problems using dot sensitivity. The initial designs only consist of air, and ferromagnetic dots are generated at proper spots with optimization process. The adaptive level set technique is applied to handle the boundary changes and dot generations.

A. Example 1: Wireless Power Transfer System

The design problem of a wireless power transfer system is performed to maximize mutual inductance. The design goal is to optimize the topology of the ferromagnetic core to get the maximum mutual inductance between the primary and the secondary windings. The objective function of this application is taken as

$$F_1 = \int_{\Omega_{2,1}} A_z d\Omega - \int_{\Omega_{2,2}} A_z d\Omega \tag{5}$$

where A_z is magnetic vector potential and $\Omega_{2,1}, \Omega_{2,2}$ are the domains of the secondary winding respectively as shown in Fig 1. This Objective function is equal to magnetic flux passing through the secondary winding.

B. Example 2: Magnetic Shielding in Specific Area

Topological optimization of magnetic shielding system is implemented to minimize magnetic flux in specific area. The objective function of the numerical model is written as

$$F_2 = \int_{\Omega_{obj}} |B|^2 d\Omega \tag{6}$$

where B is magnetic flux density and Ω_{obj} is the specific region for minimizing magnetic flux as shown Fig. 3.

C. Numerical Results

Fig. 1 and Fig. 3 show the evolution of the ferromagnetic material and magnetic flux lines. Both initial designs only consist of air, and ferromagnetic materials are created at proper spots for optimization of objective function. Fig. 2 and Fig. 4 show that both objective functions go to optimum values with iteration of optimization process.

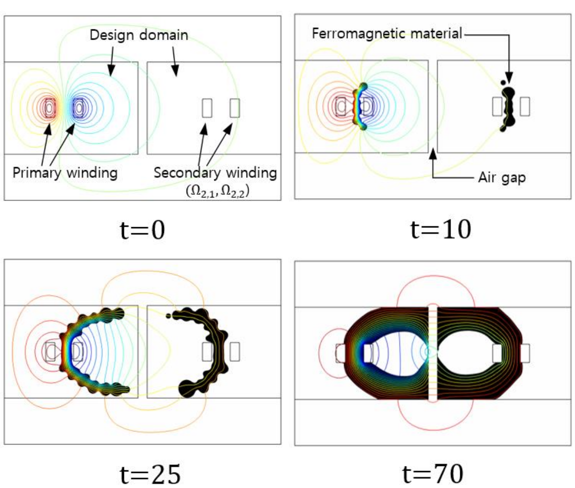

Fig. 1. Shape evolutions of the wireless power transfer system.

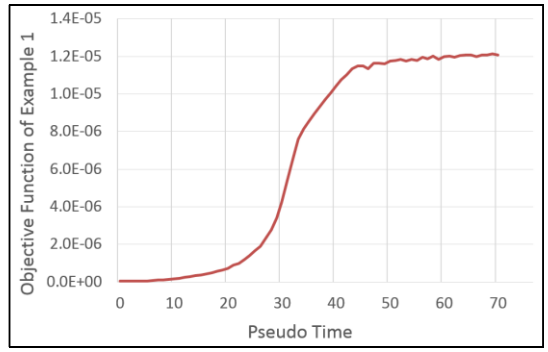

Fig. 2. Variation of objective function of the wireless power transfer system.

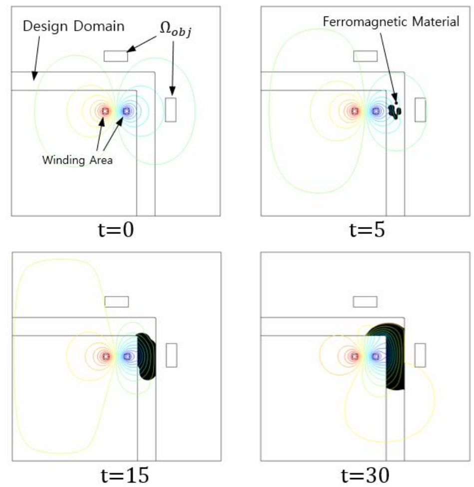

Fig. 3. Shape evolutions of the magnetic shielding system.

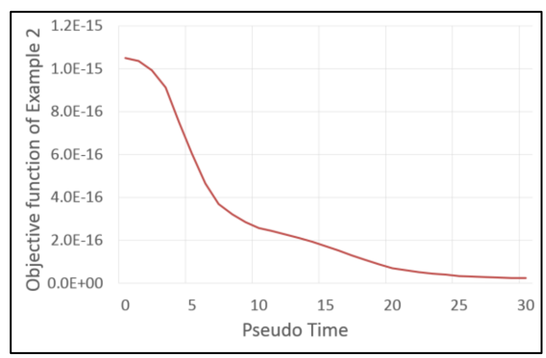

Fig. 4. Variation of objective function of the magnetic shielding system.

IV. References

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