

# Optimal Shape Design of Magnetic Actuators for Magnetic and Dynamic Characteristic Improvement

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(Received 23 May 2011, Received in final form 14 June 2011, Accepted 15 June 2011)

**This study introduces a new topology optimization scheme combining the genetic algorithm (GA) with the on/off sensitivity method for the magnetic actuator core and the armature design. The design process intended to maximize the first eigen-frequency of the armature part and the magnetic actuating force acting on the armature simultaneously. GA based optimal design was carried out to obtain the initial structure and the modified on/off sensitivity method was succeeded to accelerate the design process. Final results show tens of percent improvement in actuating force as well as the first eigen-frequency of the armature.**

**Keywords:** magnetic actuator, topology optimization, genetic algorithm, on/off sensitivity method, finite element analysis

## 1. Introduction

Topology optimization has been regarded as an attractive design scheme to set up the basic structural outline in an initial design stage without any prior knowledge not only for elastic problems [1] but also for magnetic field problems [2]. The ordinary topology optimization process generally employs a gradient based sensitivity analysis for the design variable update. However, in case of multi-physics problems in which more than two physical governing equations must be taken into account, it is hard to adopt the gradient based approach because it is difficult to apply several sensitivity values obtained from different objectives into simultaneous design variable update. The genetic algorithm (GA) based topology optimization [3] can be an alternative choice; however, it is suffered from expensive computation cost through the random biological process such as selection, crossover and mutation in spite of recent great enhancement of computation power.

This study suggests a modified topology optimization scheme combining GA with so called the on/off sensitivity method [4] for magnetic actuator core and armature design. Design objectives are established as maximizing the magnetic actuating force and first eigen-frequency of

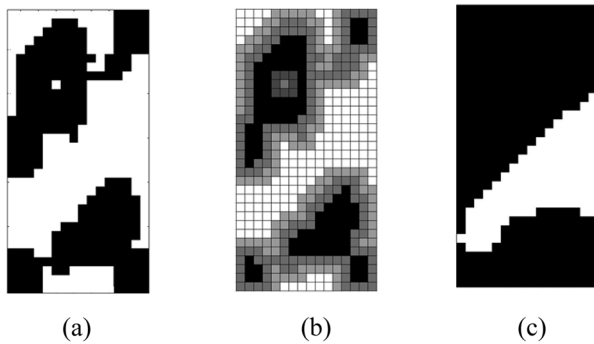
the armature part, obtained from magnetic field analysis and structural dynamic analysis, respectively, i.e., from multi-physics analysis. The on/off sensitivity method defining an element existence according to the sensitivity difference between the exist and the not-exist cases is also modified just to be applied along structural boundaries to accelerate optimization convergence [5].

## 2. Optimization Algorithm by GA and On/off Sensitivity Method

GA based topology optimization is also composed of general GA procedures such as mutation, crossover and fitness evaluation. Also, effective conversion of chromosomes (genotype) into structural topology (phenotype) is an important issue. The blurring technique, which is giving the density weight to the design domain elements and large clusters are determined according to the volume fraction, is adopted to avoid randomly distributed small spots of solid [5]. Seed element concept which defines infeasible design domain is also applied to secure magnetic flux path along the structure [3, 5].

Since GA based topology optimization requires expensive computational cost, the on/off sensitivity method, firstly proposed Im *et al.* [4], is modified. Ordinary on/off method can guarantee objective value improvement during the optimization process but still needs severe computa-

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**Fig. 1.** Application of the modified on/off method: (a) original structure, (b) on/off method application area (represented in gray) and (c) optimal structure.

tional time because the fitness evaluations as many as the number of design variables are necessary at each of iterations. Therefore, the on/off sensitivity is applied only to the surface of a structure or along the hole-area as represented in gray color in Fig. 1(b). Fig. 1(a) and (c) show the original and optimal structure, respectively. Fig. 2 displays the optimization procedure. 10 initial structures are generated and GA based topology optimization has been carried out for the first 30 iterations. The on/off sensitivity method is succeeded to accelerate the process.

### 3. Numerical Results

The design objective of the magnetic actuator is set to maximize the first eigen-frequency of the armature as well as to maximize the magnetic actuating force as

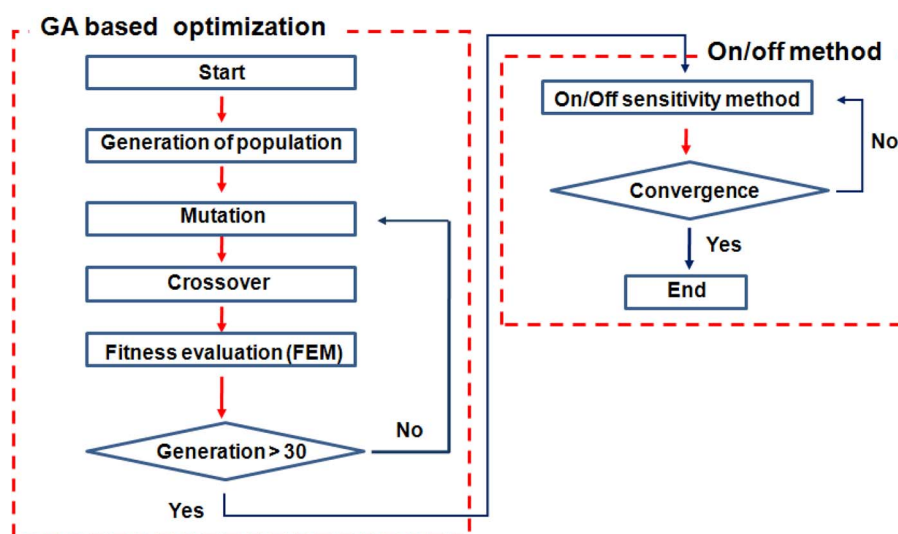
$$\text{maximize } f = w \times f_1/f_{1,initial} + (1-w) \times f_2/f_{2,initial} \quad (1)$$

where  $f_1$  is the magnetic force applied to the armature and  $f_2$  is the first eigen-frequency of the armature.  $w$  represents the weighting factor ranging from 0 to 1 and it is determined as 0.7 for the optimal model. ‘initial’ means each initial value of  $f_1$  and  $f_2$  for normalization.

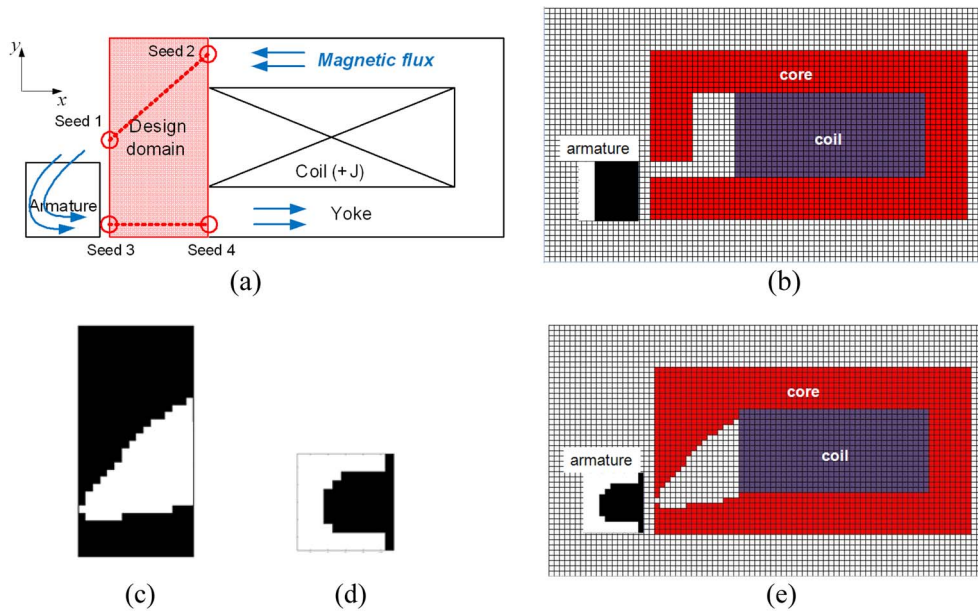
Fig. 3(a) shows the asymmetric actuator model with the design domain definition and four seed element locations taking into account of the magnetic flux flow. The design domain of the armature is restricted to the left portion of the yoke because its shape is essential to determine the magnetic flux path associated with the armature. Fig. 3(b) shows the finite element model of the initial actuator and its actuating force and first eigen-value of the armature are computed as 1112.22 N/m and 12454.55 Hz, respectively. Fig. 3(c) is the optimal shape of the yoke only to maximize the magnetic actuating force. It is computed as 1986.90 N/m in case of keeping the original rectangular shape of the armature with the volume fraction constraint of 0.7. Fig. 3(d) shows the optimized armature shape maximizing first eigen-frequency and the actuating force simultaneously with the optimized yoke shape given in Fig. 3(c) and its volume fraction is set to 0.5. The force becomes 1950.740 N/m, decreased a little due to the armature shape change, while the eigen-frequency is increased to 16700.21 Hz. Fig. 3(e) represents the final optimized model of the actuator.

### 4. Conclusion

The suggested method combined of GA with the on/off sensitivity method is verified as an effective method for multi-physics topology optimization. Computational cost is also reduced rapidly in comparison with the case where



**Fig. 2.** (Color online) Flowchart of the suggested topology optimization process.



**Fig. 3.** (Color online) Optimization results of the actuator: (a) schematic diagram of the actuator, (b) initial actuator model, (c) optimal shape of the yoke at the design domain, (d) optimal result for the armature and (e) final optimal shape of the actuator.

only GA is used due to the reduction of the total iteration number.

### Acknowledgment

This work was supported by Mid-career Researcher Program through NRF grant funded by the MEST (No. 2011-0000117).

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