Fundamental Study on Density-Based Topology Optimization Methods in Electromagnetic Fields

Taiki Kuze
Hideaki Nagamine
Tadashi Yamaguchi

(Gifu University)

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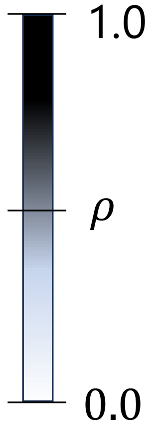
Outline

- Density-Based Topology Optimization Methods
- Background
- Purpose
- Propose Methods
- Analysis Model
- Consideration
- Conclusion

Density-Based Topology Optimization Methods

Topology optimization methods is widely used in the field of design on electromagnetic devices.

Initial Topology　　Updating　　Optimized Topology



$\rho^{k+1} = \rho^{k} + \Delta\rho^{k}$　　ρ : density

$$\mu = \mu_0\{1 + (\mu_r - 1)\rho^n\}$$

Background

Density-based topology optimization has the following issues:

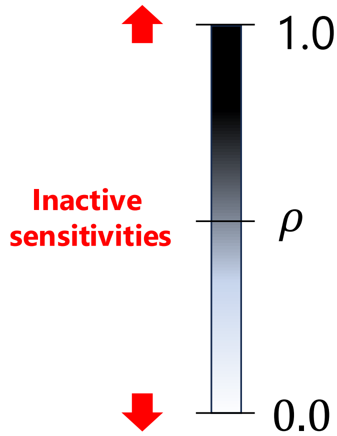
- **Inactive sensitivities at density bounds (ρ = 0 or 1)**
- **Vanishing sensitivity in low-density regions**

These problems degrade convergence and solution quality

①*Inactive sensitivities at density bounds*

Sensitivity may suggest decreasing density at ρ = 0 or increasing density at ρ = 1

→ Inactive sensitivity updates
→ Causes slow convergence



②*Vanishing sensitivity in low-density regions*

Permeability interpolation:

$$\boldsymbol{\mu = \mu_0\{1 + (\mu_r - 1)\rho^n\}}$$

$$\boldsymbol{\frac{\partial \mu}{\partial \rho} \propto n\rho^{n-1}}$$

→ Gradient vanishes as ρ → 0
→ Design variables fail to update
→ Optimization stagnates

Purpose

To improve both:

・Update quality (Eliminating unnecessary updates)
・Update quantity (Ensuring gradient availability)

→ Achieve effective design variable updates

Propose Methods

For Problem 1
Sensitivity Enhancement : Method(a)
For Problem 2
Avoidance of zero sensitivity (Introduction of ρ_{min})
: Method(b)

→ Simultaneous control of update quality and quantity

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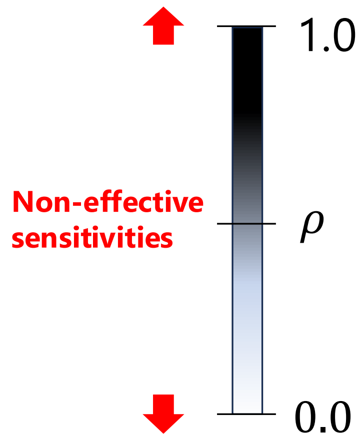
The Method (a) : *Sensitivity Enhancement*

Conditional sensitivity:

$\rho = 0$ and $\partial W/\partial \rho > 0$ → set to 0
$\rho = 1$ and $\partial W/\partial \rho < 0$ → set to 0

→ Removes unphysical updates



Effects:
・Improving convergence stability
・Eliminating unnecessary updates

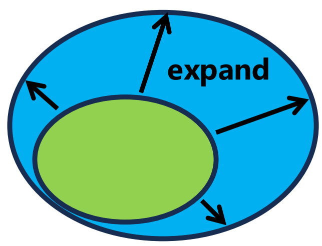
The Method (b) : *Avoidance of Zero Sensitivity*

Introduce minimum density ρ_{min}

$$\mu(\rho) = \frac{(1-\rho^n)\mu_{air} + (\rho^n - \rho_{min}{}^n)\rho_{iron}}{1-\rho_{min}{}^n}$$

$$\mu(\rho_{min}) = \mu_{air}$$
$$\mu(1.0) = \mu_{iron}$$

→ Restrict: $\rho \geq \rho_{min}$



Search domain
for the solution

Effects:
・Preventing zero gradient
・Ensuring updates of design variables

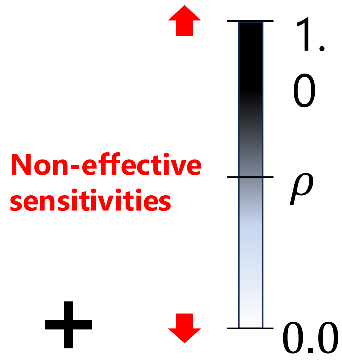
Integration of Methods

method(a): eliminates unnecessary updates
method(b): ensures necessary updates

(a) only:
→ update becomes insufficient

(b) only:
→ noisy updates remain

(a) + (b):
→ stable and continuous update



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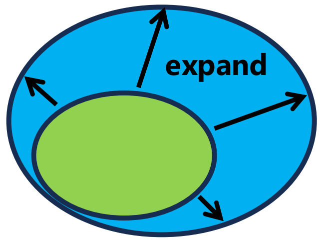
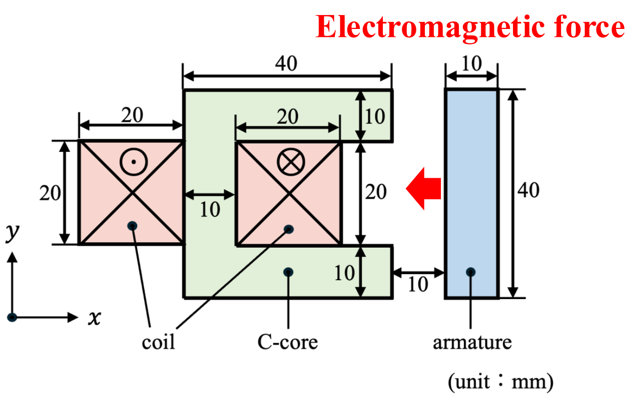


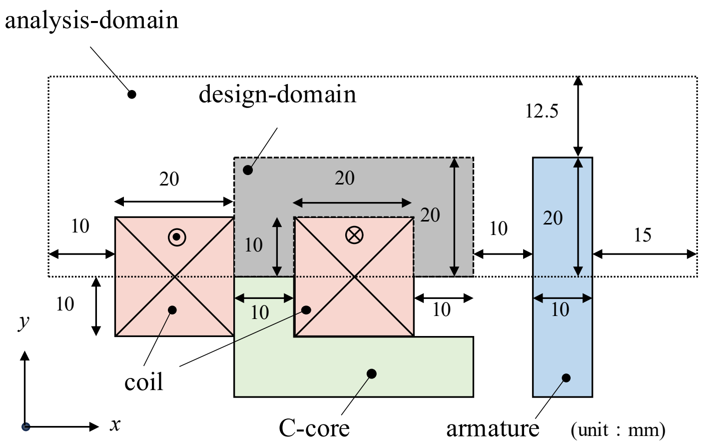
Search domain for the solution

Analysis Model (1)

To verify the effectiveness of the proposed methods, we apply them to the following model:

2D C-core model : Objective : Minimize electromagnetic force





Analysis specifications

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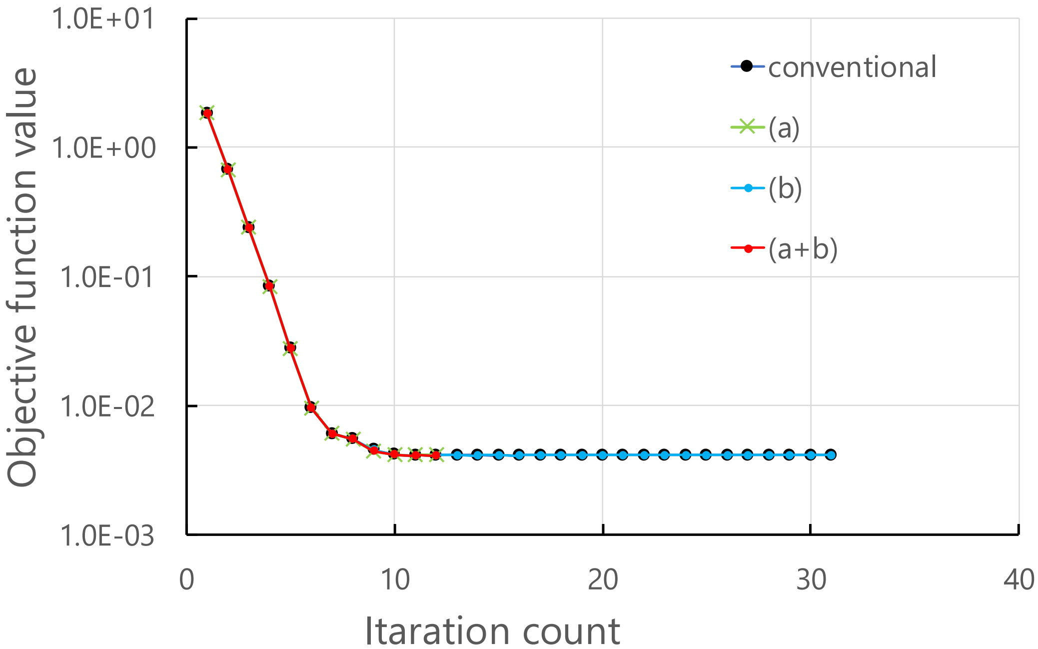
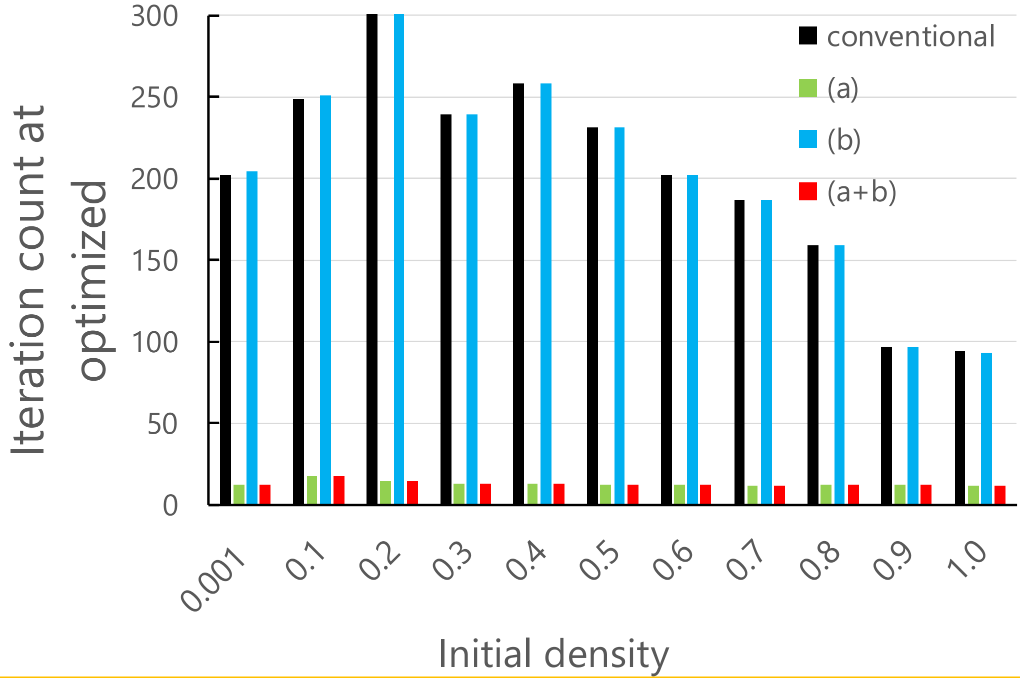
Number of elements	13,650
Number of nodes	13,926
Number of elements in design domain	2,400
Current density	2.0e6
Relative permeability of armature	1,000

- ・Bilinear quadrilateral elements
- ・Fortran implementation
- ・ICCG Method
  Convergence criterion :10^{-12}

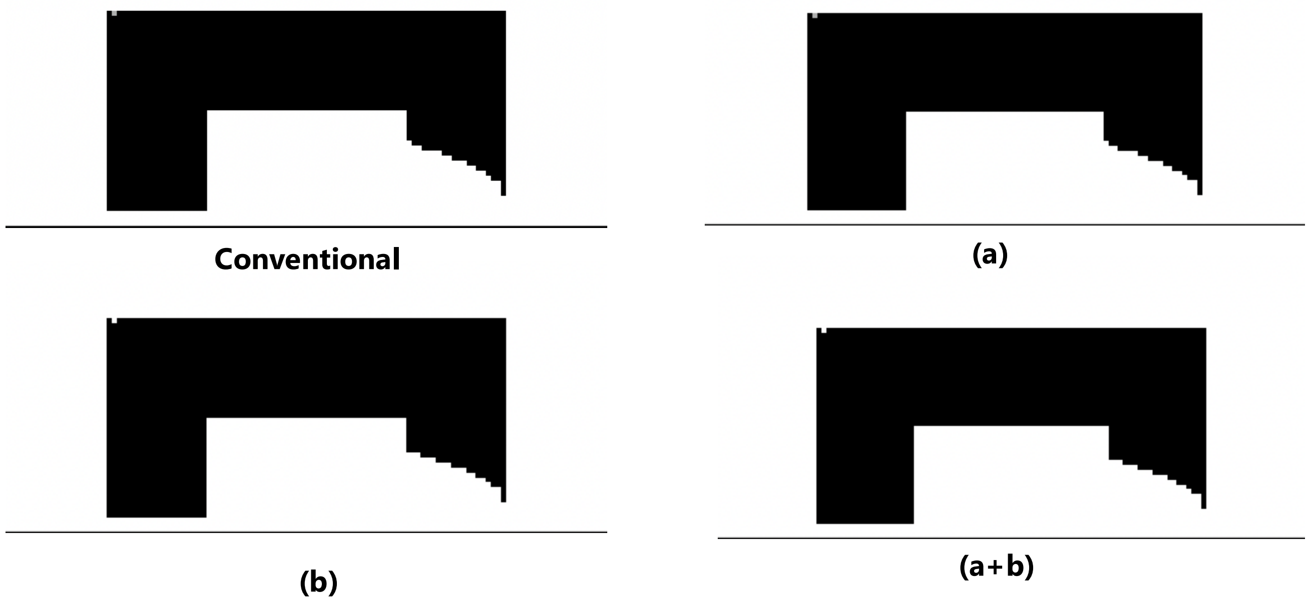
Result : Objective value



Result : Number of Iterations



Result : Optimized Shape



Conclusion

・Two issues in density-based update are identified
・Corresponding methods are proposed

→ Both update quality and quantity are improved
→ Optimization performance is enhanced

Thank you for listening.

Yamaguchi・Nagamine Laboratory, Gifu University, Japan