

Toward multi-material topology optimization of doubly-excited electrical machines using recursive material interpolation

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Summary. In the field of Multi-Material Topology Optimization (MMTO) of electrical machines, considering both permanent magnets and multiple electrical phases simultaneously within the same design domain is difficult due to their different natures. As an extension of density methods, this work proposes a general material interpolation framework able to dissociate the materials regarding their nature, relying on a recursive implementation.

1 Introduction

Doubly-excited electrical machines contain both permanent magnets and excitation coils and are of interest in traction applications [2]. To design them, optimization strategies should be used to fulfill exigent specifications. Topology optimization, such as density-based methods [4], provides the largest design freedom. The problem to solve is the following:

$$\begin{aligned} & \text{Minimize} && f(a(\rho)) \\ & \text{Subject to} && \rho : \Omega \rightarrow \mathcal{D}, \end{aligned} \quad (1)$$

with f the cost function that depends explicitly on the physical state a , which itself depends implicitly (through physical equations, e.g. magnetostatics) on the design variable ρ mapping the optimization domain Ω to the interpolation domain \mathcal{D} described in the next section.

2 Formalism

In general, \mathcal{D} is a convex polytope that supports differentiable interpolations of the material properties, each vertex being associated with one of the n candidate materials. The interpolated material property $\tilde{\kappa}$ is therefore built from the corresponding property κ_i of each material i , shape functions ω_i [5], and possibly penalized by a penalization function P

$$\tilde{\kappa}(a, \rho) = \sum_{i=1}^n P(\omega_i(\rho)) \kappa_i(a). \quad (2)$$

The MMTO problem (1) can then be solved with a projected gradient approach [1]. For practical reasons, we have $\dim \mathcal{D} \leq 3$, which limits the number of different material natures (e.g. several electrical phases

on the same plane and ferromagnetic material in the third dimension). A way to extend the dimension of \mathcal{D} is to use “interpolation of interpolations”, defined recursively through a rooted tree:

$$I_{(k,i)}(a, \rho) = \sum_{l=1}^{n_{(k,i)}} P(\omega_{(k,l)}(\rho_{(k,i)})) I_{(k+1,l)}(a, \rho), \quad (3)$$

where (k, i) is an index (for example, the Neveu notation [3]) associated to the local interpolation domain that depends on the current recursion level k and the i -vertex of the parent interpolation domain. The root $I_{(k=0)}$ represents the interpolated material property, and the tree leaves are the candidate materials’ properties. Similar structures obtained by the chain rule define the derivatives of (3) with respect to a and ρ .

3 Conclusion and applications

This work presents a recursive extension of the material interpolation formalism used in density-based topology optimization. This framework has been implemented, and the results of the MMTO of permanent magnet, wound field, and doubly-excited machines will be presented in the full paper.

References

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