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Multi-material topology optimization of a rotating electrical machine with a density-based method

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Context and motivations

Topology optimization has become a popular tool especially in mechanical engineering. Many interesting methods have been developed [1]. Density methods like SIMP have been introduced in electrical engineering by [2], and are now widely used to design electrical actuators. Multi-materials problems involving source distribution have been addressed [3, 4]. However, most of the work focuses only on single parts of the machine (rotor, stator teeth), and a few papers such as [5] deal with the coil distribution problem within the stator.

This work presents a density-based method which could be used to separately optimize the rotor and the stator of a rotating machine, with the future objective to optimize both from scratch.

Magnetostatics equation

2D vector potential local formulation

\[ \nabla \times \left( \frac{1}{\mu} \nabla \phi \right) = \nabla \times \mathbf{J} \]

\[ \phi = \frac{1}{\mu} \mathbf{B} \cdot \mathbf{n} \]

\[ \mathbf{J} = \nabla \times \mathbf{A} \]

\[ A_z = \frac{1}{2} \left( \mu_0 H_z + B_z \right) \]

\[ B_z = \mu_0 H_z \]

\[ H_z = \frac{1}{\mu_0} \frac{\partial B_z}{\partial z} \]

Intermediate materials should be eliminated during the optimization process, by the use of penalization (SIMP, RAMP [1]), thresholding, constraints, etc.

Optimization of SRM rotor

Filtering inspired by ESO procedure [7] was applied: materials which carried few flux replaced by air. Then, flux barriers [6] appear clearly and correspond to industrial design like ABB® SRM:

Optimization of PMSM stator

4-materials topology optimization [4] was performed on a one-phase PMSM stator with uniform initialization. Two densities per element were used. The convergence is slow near the airgap, so each gradient pair of elementary terms was normalized. As it is multiplied by a symmetric definite matrix, it remains a descent direction and leads to an asymmetric design.

Conclusion and outlook

Encouraging results with flux barriers were obtained for the SRM rotor optimization. The multiamaterial PMSM stator optimization of the stator leads to intriguing asymmetrical design, which is maybe a local optimum. Further research is needed to compare this topology with established ones. It is also necessary to improve the robustness of the method especially for high current density, before optimizing both the rotor and the stator. Multiphysics considerations will be taken into account in future work.

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References