

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

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Topology optimization (TO) has been extensively studied in the past decades especially in mechanical engineering. Among different techniques, density-based methods have become very popular. In electrical engineering, TO has been applied essentially to linear actuators [1] or machines rotors [2][3], but few works such as [4] deal with the coil repartition within the stator of rotating machines.

In this study, we investigate a density-based topology optimization method, which aims to maximize the average torque of a rotating electrical machine from random or uniform initial material repartition. Material properties such as magnetic permeability or current density are interpolated on densities between each material to obtain a differentiable optimization problem, using SIMP or RAMP [5] for example. A custom magnetostatic finite element solver was implemented on MATLAB[®]. It takes into account the non-linearity of magnetic materials with Newton-Raphson method. The optimization algorithm relies on sensitivities obtained by the adjoint variable method (AVM) [6]. The methodology was performed for two test cases :

- optimization of iron/air repartition within the rotor of a synchronous reluctant machine (SRM)
- optimization of coils/iron/air repartition within the stator of a one phase permanent magnet synchronous machine (PMSM).

In the air/iron case, a filtering technique inspired by ESO [7] is applied: iron which carries few magnetic flux is removed. No filtering was applied in the multi-material case, but a normalization of the gradient was investigated.

As a result, we obtain flux barriers [8] for the optimized SRM rotor, which correspond to industrial designs. However, some convergence issues happened, especially for multi-material optimization. The gradient normalization helps preventing this phenomenon but leads to surprising assymetric designs, which need further investigations. It is also necessary to improve the robustness of the method especially for high current density, in order to optimize both the rotor and the stator. Multiphysics considerations will be taken into account in future work.

References

- [1] J. Lee, S. Lee, K. Kim and J. Lee, "Multi-Material Topology Optimization of Magnetic Actuator With Segmented Permanent Magnets". IEEE Transactions on Magnetics, no. 7 (2018), pp. 1-6.
- [2] S. Jung, J. Ro and H. Jung : "A Hybrid Algorithm Using Shape and Topology Optimization for the Design of Electric Machines". IEEE Transactions on Magnetics, no. 3 (2018), pp. 1-4.
- [3] B. Ma, J. Zheng, G. Lei, J. Zhu, P. Jin and Y. Guo : "Topology Optimization of Ferromagnetic Components in Electrical Machines". IEEE Transactions on Energy Conversion, no. 2 (2020), pp. 786-798.
- [4] T. Labbe and B. Dehez : "Convexity-Oriented Mapping Method for the Topology Optimization of Electromagnetic Devices Composed of Iron and Coils". IEEE Transactions on Magnetics, no. 5 (2010), pp. 1177-1185.
- [5] M. Stolpe and K. Svanberg, : "An alternative interpolation scheme for minimum compliance topology optimization". Structural and Multidisciplinary Optimization, no. 22 (2001), pp. 116-124.
- [6] J. S. Choi and J. Yoo : "Structural optimization of ferromagnetic materials based on the magnetic reluctivity for magnetic field problems". Computer Methods in Applied Mechanics and Engineering, iss. 49-50 (2008), pp. 4193-4206.
- [7] Y.M. Xie and G.P. Steven : "A simple approach to Structural Optimization". Computers and Structures, no. 5 (1993), pp. 885-896.
- [8] M. Martinović, S. Stipetić, D. Žarko and M. Klanac : "Comparison of Synchronous Reluctance Machines Using Topology Optimization". International Symposium on Power Electronics, Electrical Drives, Automation and Motion (2020), pp. 472-477.