The Implications of the Use of Composite Materials in Electromagnetic Device Topology and Shape Optimization

Dong-Hun Kim[1], Jan Sykulski[2], Senior Member IEEE, David Lowther[3], Member IEEE
[1]School of EE and CS, Kyungpook National University, Daegu, 702-701, Korea
[2]School of ECS, University of Southampton, Southampton, SO17 1BJ, UK
[3]ECE Department, McGill University, Montreal Quebec, H3A 2Ay, Canada
dh29kim@ee.knu.ac.kr, david.lowther@mcgill.ca, jks@soton.ac.uk

Abstract — The use of composite materials provides electromagnetic device designers with serious challenges. While such materials have the potential of allowing novel three-dimensional topologies to be used, as well as providing major advantages in recycling at the end of the lifetime of the device, little or no design experience exists in this area. This paper proposes the use of sensitivity based topology optimization as a methodology for assisting designers in this task.

I. Introduction

The development of new materials, particularly powdered magnetic steels, and improved permanent magnets has the potential of changing the design of electrical machines. These materials are likely to become more common in the foreseeable future as designers are required to consider the entire life cycle of a machine from manufacture to recycling.

Composite materials bring with them a range of properties which will have a considerable impact on electromagnetic device design. For example, most electrical machines up to this point have been pseudo-two-dimensional in their structure, i.e. they have been constructed from laminated materials which, naturally, force a translational structure on the permeable components. The need for laminations is imposed by the need to reduce the eddy currents which can be generated when the material is subjected to time-varying magnetic fields. Composite materials, being constructed from insulated permeable particles, naturally restrict the eddy currents in all dimensions and this removes the translational constraint. In addition, the manufacturing processes for a device are nearer to those for injection moulded structures then traditional electromagnetic device assembly.

The major disadvantage of such materials is seen as their (relatively) low permeabilities when compared to conventional magnetic steels and this means that more material is required to carry the required fluxes in the device. This problem might be overcome by making use of truly three-dimensional structures; however, little experience exists in creating these.

The goal of this paper is to describe the application of a sensitivity based topology design process.

II. Sensitivity-based Topology Design

To deal efficiently with topological optimization problems in three dimensions, a new algorithm for the sensitivity-based topology design is introduced. The topological gradient $G(r)$ gives information on the opportunity to create a small hole $B(r,d)$ with radius d, centered at r belonging to the domain Ω

$$G(r) = \lim_{d \to 0} \frac{\Psi_{obj}(\Omega \backslash B(r,d)) - \Psi_{obj}(\Omega)}{\delta(\Omega)} \qquad (1)$$

where Ψ_{obj} is an objective function and $\delta(\Omega)$ is the area difference of the domain after and before the small hole is introduced. In practice, the domain occupied by the composite material is initially divided into finite elements. The elements are stored by their respective value of G and the 'lowest' elements are removed at each step according to the volume ratio given. The process continues until the volume constraint is encountered or the optimum of the objective function achieved. It should be pointed out that the proposed scheme is not expensive in terms of computational costs because it does not require intermediate states, nor any penalty functions for the material used.

III. Results

Fig. 1 shows the result of the topology and shape optimization of a conventional, laminated electrical machine rotor with the goal of minimizing the cogging torque by utilizing the continuum design sensitivity analysis (CDSA) [1]. When adopting composite materials, new topologies of the pole face by the proposed method will be presented.

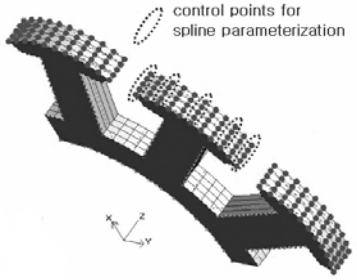

Fig.1. Optimized rotor structure showing control points used for pole face shape [1].

IV. Conclusions

The paper discusses the issues related to the topological design of electromagnetic devices using composite materials. By using a CDSA approach, the possible topologies can be explored almost automatically. The full paper will examine the trade-offs between conventional and composite materials.

V. References

[1] D.-H. Kim, J. K Sykulski, D. A .Lowther, "Design optimisation of electromagnetic devices using continuum design sensitivity analysis combined with commercial EM software," *IET Science, Measurement & Technology*, 2007, 1, (1), pp.30-36.