Finite-Element Modeling of Multi-turn Coils Using a Thin Wire Approximation

Jonathan Velasco*, François Henrotte*†, and Christophe Geuzaine*

*Department Electrical Engineering and Computer Science (ACE), Institut Montefiore, University of Liège, Belgium
† Catholic University of Louvain (UCL), EPL-iMMC-MEMA, Louvain, Belgium
E-mail: jonathan.velasco@uliege.be

***Abstract*—This paper presents an efficient finite-element technique to solve skin- and proximity effects in multi-turn coils at a broad range of frequencies, without the need to discretize the wires explicitly. In two-dimensions (2D), round wires are reduced to single points within the finite- element mesh, and the proposed semi-analytical method exploits analytical solutions for the accurate calculation of the coil impedance. The method is validated in 2D magnetodynamics frequency-domain.**

***Index Terms*—impedance, multi-turn inductors, proximity effect, skin effect**

I. Introduction

The accurate solution of the field problem in conducting domains presents challenges as the frequency increases, and phenomena such as skin- and proximity effects call for a fine discretization of the computational domain (e.g., finite-element mesh). Hence, the memory resources needed might exceed the available ones, making the problem computationally prohibitive at higher frequencies.

This paper proposes an inexpensive technique to replace classically modeled round conductors as points in a finite-element mesh. Although the internal discretization of wires is disregarded, relevant phenomena such as skin- and proximity effects are taken into account. The proposed method is a hybrid technique that arises from joining the analytical solution of a single wire in isolation into the FE model. This approach is addressed as the *semi-analytical model*, whereas classically modeled solid-conductors will be addressed as the *full model*, due to their all-inclusive nature.

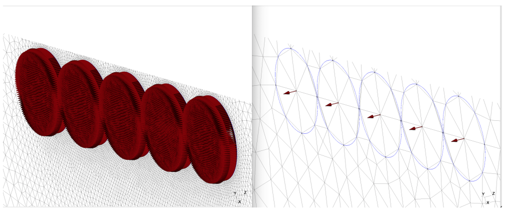

Fig. 1. Current density distribution: Full Model (Left), Semi-analytical Model (Right)

II. Thin Wire Approximation

A vanishing radius introduces a singularity in the finite-element model that requires appropriate treatment of the circulation integral terms arising from the weak formulation on the conducting nodes Ω_{LR}, representing thin wires. Hence, the *sleeve* region Ω_{SL} made of the finite elements in the mesh having at least one node on Ω_{LR} needs careful consideration [1] . In Fig. 1 the semi-analytical model depicts a so-called "*structured*" sleeve, where symmetry of the sleeve is ensured, however, ultimately the size and shape of the sleeve will be defined by the meshing tool used (e.g., Gmsh). In this case the sleeve will be described as "*unstructured*".

The idea behind the method is solving the Maxwell problem twice on the sleeve domain of each coil turn, allowing the brute force subtraction of the singularity in the FE model. This *truncation* approach, removes the input source and enables the solution of the magnetic vector potential as a background source instead. Hence, the solution can be reconstructed, as each turn can be solved analytically (1D approximation) as an isolated wire, and the contribution of the background field on each turn can be added by the accurate calculation of the magnetic flux.

III. Preliminary Results

Fig. 2 shows good agreement between the full model, compared against the semi-analytical method.

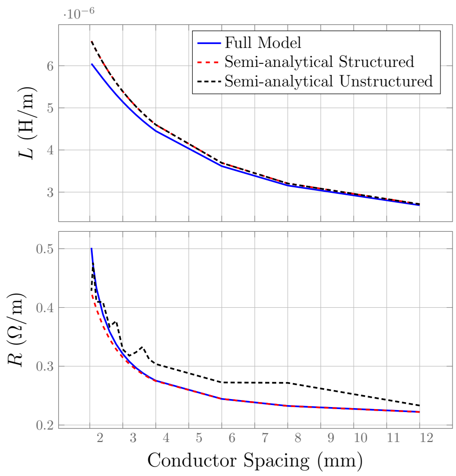

Fig. 2. Impact of Conductor-spacing Between 5-Turns on Impedance for Structured and Unstructured Sleeves at 1MHz

References

[1] J. Velasco, F. Henrotte, and C. Geuzaine, "Finite-Element Modeling of Thin Conductors in Frequency Domain", IEEE Transactions on Magnetics; 56(4):1-4., 2020.