Influence of the Geometrical Uncertainties on the RLC parameters of Wound Inductors Modeled Using the Finite Element Method

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***Abstract*—In this work, we highlight the influence of geometrical uncertainties (winding pattern and wire diameter) on the RLC parameters of wound magnetic components. To that end, the finite element method is embedded in a Monte Carlo simulation in order to compute probability distributions of the parameters. An algorithm to randomly generate realistic winding configurations is also proposed.**

***Index Terms*—Finite elements, geometrical uncertainties, Monte Carlo simulation, RLC parameters, wound inductors.**

I. INTRODUCTION

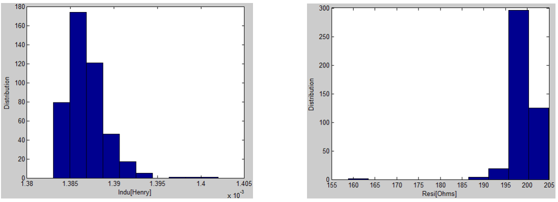
The numerical modeling of wound magnetic components typically used in high frequency switch-mode power supplies (up to several MHz), is still challenging among the scientific community. The fast switching operation implies the occurrence of undesirable phenomena which are still difficult to model: skin and proximity effects, parasitic capacitances, higher magnetic losses, etc. Despite recent efforts oriented in this direction, some differences are still observed between numerical simulations and experimental measurements conducted on high-frequency wound magnetic components [1]. To some extent, such discrepancies are caused by material and geometric uncertainties. For instance, the conductor positions in the winding area window may not follow the idealized regular pattern (e.g. orthogonal or hexagonal), but are rather subject to uncertainties. The wire diameter may also vary due to the crushing of the surrounding insulating material. In addition, the permeability of the ferrite magnetic core is usually not known with an accuracy higher than 20%. The Finite Element (FE) method has recently been adapted/employed to quantify these stochastic effects, in the case of geometric uncertainties in electrical machine windings [2] and stator/rotor dimensions [3] for instance. In this work, we focus on the geometric uncertainties linked to the wire diameter and the winding pattern in high frequency inductors, and on their effect on the RLC parameters over a wide frequency range. The FE method, embedded in a Monte Carlo simulation, is employed to that end.

II. METHODOLOGY

Two decoupled FE models are implemented to extract the RLC parameters: a 2D magnetodynamic $\boldsymbol{a}$-v formulation with circuit coupling and massive conductors is employed for computing the resistances and inductances (with $\boldsymbol{a}$ the magnetic vector potential and v the electric scalar potential), whereas a 2D electrostatic formulation with floating potentials is used to obtain the parasitic capacitances [4]. These models are embedded in a Monte Carlo simulation to obtain relevant statistics about R, L and C. Random realistic configurations of the windings are generated using a novel algorithm adapted from [5] and initially proposed for the deployment of mobile sensor networks. It is based on the iterative evolution of the winding from a random initial configuration towards a local equilibrium, thanks to the action of appropriate forces between the conductor centers. The influence of turn insertions/swaps between adjacent layers (which can occur, for instance, if the wounding procedure is manually performed by an operator) is also quantified by adapting the corresponding circuit equations. Additionally, the wire diameter follows a uniform distribution computed from manufacturer data (maximum and minimum dimensions of the wire diameter, etc.).

III. PRELIMINARY RESULTS

The methodology is illustrated on a 2D axisymmetric 81-turns inductor, made of wire (ϕ0.315mm) and of ferrite core with a gap (0.24mm of thickness). Figure 1 shows for instance the distributions of R and L at a frequency of 1MHz. A splitting of the distribution is observed, which is attributed to winding configurations with significant holes. The results will be discussed in the full paper over a wider frequency range, and will include the parasitic capacitance modeling.



(a) Inductance (L) (b) Resistance (R)

Fig. 1: L and R distributions at 1MHz

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