A Hybrid Approach using Monte Carlo Simulation and Polynomial Chaos Expansion for geometrical and material uncertainties propagation in the extraction of RL parameters of wound inductors

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OBJECTIVES - Propagation of geometrical and material uncertainties using polynomial chaos expansion (PCE) combined to Monte Carlo (MC) simulation in order to compute *RL* parameters of wound inductors with the Finite Element (FE) method.

CONTEXT

The fast switching operation of wound magnetic components implies the occurrence of undesirable phenomena (skin and proximity effects, parasitic capacitances, higher magnetic losses, etc.), witch still challenging to model . Despite all design efforts, some differences are still observed between numerical simulations and experimental measurements. Such discrepancies can be caused **by geometric and material uncertainties.** To analyze their influence, we need fast non intrusive stochastic methods in order to get some statistics on outputs of the system. To that end, a hybrid approach is proposed for the propagation of these uncertainties.

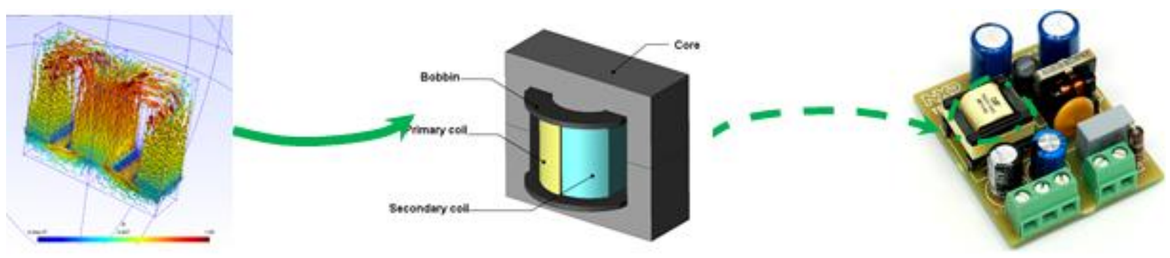


Figure1. Illustrating design process of wound magnetic components with their encontered challenges

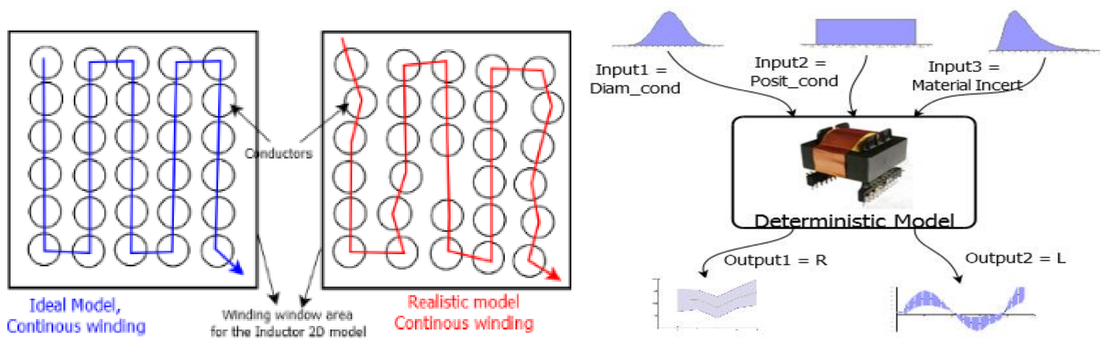


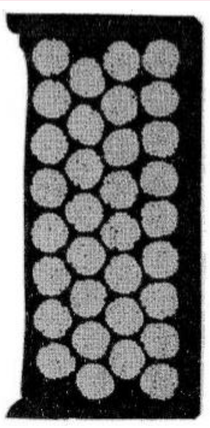
Figure 2. Realistic winding pattern (left) and the general approach for uncertainties propagation (right)

APPROACHES & TOOLS

Due to the large number of random variables in the inputs of the FE model, the use of PCE may lead to a large number of PCE evaluations (curse of dimention) in order to sufficently mimic the reference model. This issue can be compensate by using MC simulation in order to determine some model responses from the chosen experimental design. Therafter the surrogate model may be computed thanks to PCE like in the interpolation problem.

To modelize the geometrical uncertainties due to the positions of conductors, a new methodology based on the virtual reproduction of the manuel wounding process is used in order to avoid some drawbacks related to the deployment of conductors using standard approaches.

To the other hand, the magnetic permeability and the airgap of ferrite core could be considered as random variables with uniform distributions.



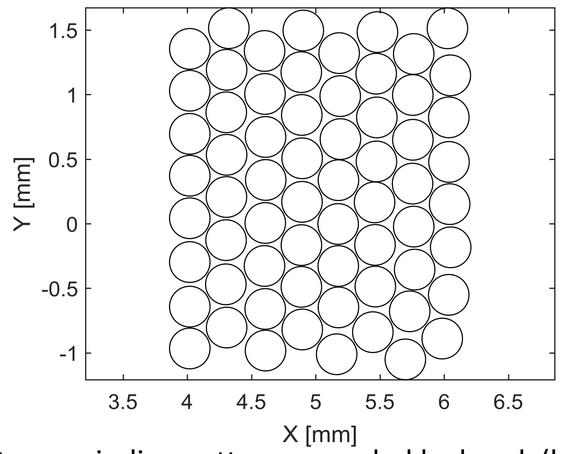


Figure 3. Section of a 32-turns winding pattern wounded by hand (left) and illustrating the winding building algorithm on a 81-turns inductor (right)

MODELLING WINDING PATTERN GEOMETRICAL UNCERTAINTIES

- Wound inductor of 32-turns around a ferrite core (with an airgap).
- Construction of winding : turn after turn, and for the first layer, uncertainties are carried by *Y* component for conductors positions.
- Conductors of the second and followwing layers are considered tangent to two conductors of the previous layers. The last conductors of these layers have an angular uncertainty arround their ideal positions.
- At each step, need to check if conductors overlap and reajust their positions in order to keep always two points of tangent with others conductors of the same or previous layer.

RESULTS & COMMENTS

- The dispersion of *R* parameter increases with the frequency, which is justified by skin and proximity effects.
- The shape of distributions remains the same along the frequency for both *RL* parameters : almost uniform for inductance and normal for resistance.
- The parameter *L* is well fitted with the PCE than *R* due to his low dispersion around the mean value. However, one observes dispersions of points around the bisector for *R* parameter

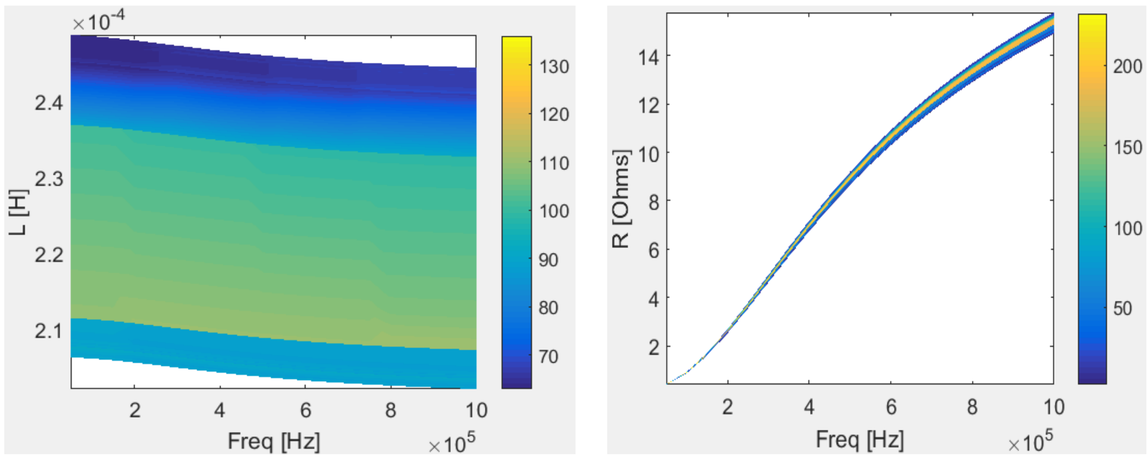


Figure 4. Simulation of *R* (right) et *L* (left) parameters vs frequency from PCE surrogates with their distributions in the form of colored cards

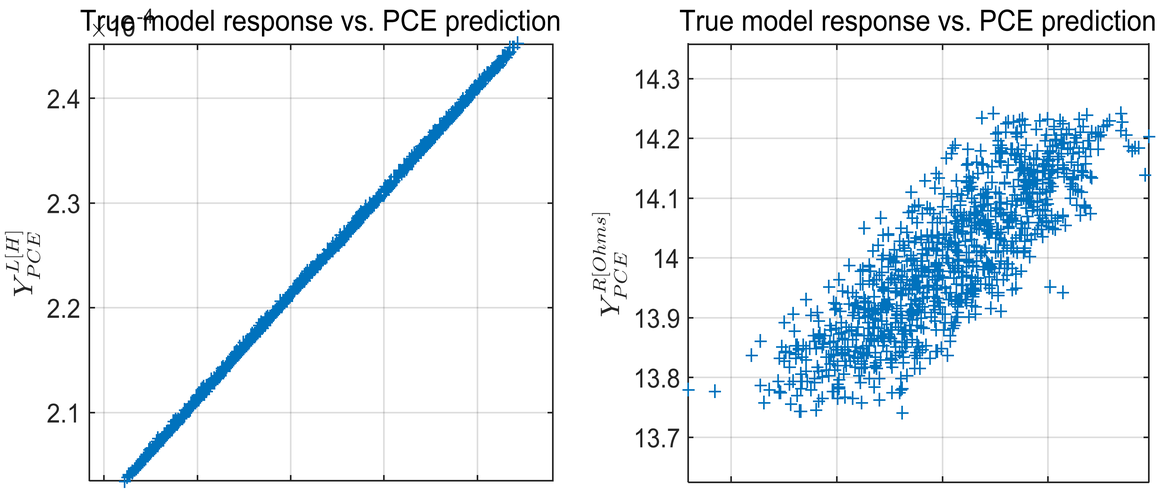


Figure 5. Cross validation of PCE metamodels at 1 MHz of *L* (left) and *R* (right) parameters

PERSPECTIVES

- Influence analysis of uncertain entries on the outputs by computing the Sobol indices.
- Need to accelerate further simulations by using a combination of intrusive and non intrusive methods.
- Influence of uncertainties on the parasitic capacitances.

CONCLUSION - This approach allows to take into account the winding pattern and material uncertainties while modelling wound inductors thanks to Finite Element Method in order to extract *RL* parameters over a wide frequency range. This is done in order to justify, for perspective works, the gap between numerical simulations through extracted parameters and the experimental measurements over this kind of components.

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