Sensibility Analysis of Inductance Involving an E-core Magnetic Circuit for Non Homogeneous Material

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Abstract

In this work, a methodology is developed, based on the application of finite element method in the frequency domain, using the software COMSOL Multiphysics®, aiming the sensibility analysis of inductance calculation involving some configurations of an E-core magnetic circuit. Such important analysis, for various geometries and considering different frequencies for the source current applied, provides sufficient information for studying magnetic phenomena, intrinsic to the problem, like: Foucault losses, frequency response, magnetic reluctance variation, skin effect and temperature distribution. A detailed description of this study is presented in this paper with an example of application involving an inductive sensor that can be used in the sense of providing parameters for a control system in a magnetic bearing.

Many problems concerning inductance calculation and consequently involving analysis of current distribution in conductive media refer to proximity effects and eddy currents. Those phenomena are responsible for changing the profile of current distribution and in general can lead to increased losses and heating of the conductive material.

Time varying electromagnetic fields in conductive media can be analyzed in terms of the current density vector, usually defined by an integral equation, whose analytical solution is possible only in simple configurations. For arbitrary complex structures dealing with non-homogeneous media, numerical procedures are employed either in time domain or in frequency domain and, among them, the Finite Element Method (FEM) can be applied.
In case of nonlinear materials, a time domain analysis is indicated to obtain accurate solutions. FEM requires a convenient mesh grid study to obtain a correct and optimized solution about the model. The optimization of the mesh is related to some specific physics characteristics, like skin depth, which determines the numbers of elements over the wave length. These characteristics exist only in specifics areas, which is enough to create a high computational solution process. The time domain analysis is another parameter that could be taken into account in computational process.

A frequency domain approach is also possible and the solution is obtained successively for different frequencies that represent the spectrum of the excitation function. The limitation of this approach is related to Gibbs phenomenon when dealing with transient analysis which leads to difficulties in correctly describing a transient excitation, especially in the case of waveforms with small rise and fall times, as a square wave, for example. The Frequency Domain study is

used to compute response of linear or linearized model subjected to harmonic excitation, therefore the magnetic non linearity of the material is neglected.

The study of many parameters that are inherent of inductance calculation, like frequency response and proximity effects, could be taken into account to develop sensibility studies in association with a proximity inductive sensor. The technology consists, fundamentally, by an oscillator circuit responsible for generating a high frequency electromagnetic filed over the inductor. The electromagnetic principle for detection is related to an interaction of the field lines with a metallic object positioned near the inductor. The approximation of the object modifies the magnetic reluctance of the system which could be detected with one external circuit.

Reference

[1] S. L. Y. Yanhua, “Analytical method for eddy current loss in laminated rotors with magnetic bearings”, IEEE Transactions on Magnetics, vol. 38, N.2, pp. 1341 - 1347, Mar 2002.

[2] C. Xu, S. Wang, G. Tang, D. Yang, B. Zhou, “Sensing characteristics of electrostatic inductive sensor for flow parameters of pneumatically conveyed particles“, Journal of Electrostatics, vol. 65, pp.582-592, 2007.

[3] L. Li et al., “Numerical treatment for time domain integral equations of thin wire structures in half-space configuration”, IEEE Transactions on Magnetics, vol. 44, No.6, pp.774-777, June 2008.

[4] L. Liangliang et al, “On-Package magnetic materials for embedded inductor applications”, International Conference on Electronic Packaging Technology & High Density Packaging, 2009.

[5] A. D. Theocharis, J. Milias-Argitis, T. Zacharias, "Three-phase transformer model including magnetic hysteresis and eddy currents effects", Dept. of Electr. & Comput. Eng., Univ. of Patras, Patras 2009.

[6] M. Hsich, Y. Hsu, "A generalized magnetic circuit modeling approach for design of surface permanent - magnet machines", Dept. of Syst. & Naval Mechatron. Eng., Nat. Cheng Kung Univ., Tainan, Taiwan 2011.

[7] K. T. Son and C. C. Lee, “Temperature measurement of high-density winding coils of electromagnets”, IET Science – Measurement and Technology, vol. 6, pp. 1-5, Sept 2012.

Figures used in the abstract

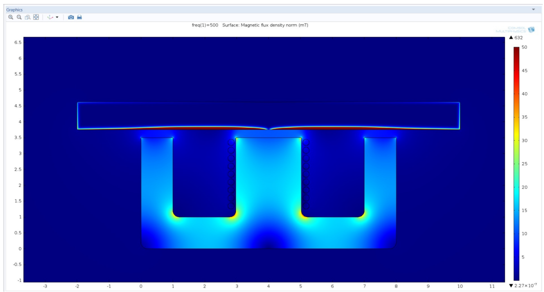

Figure 1: Distribution of the magnetic density flux in the geometry.

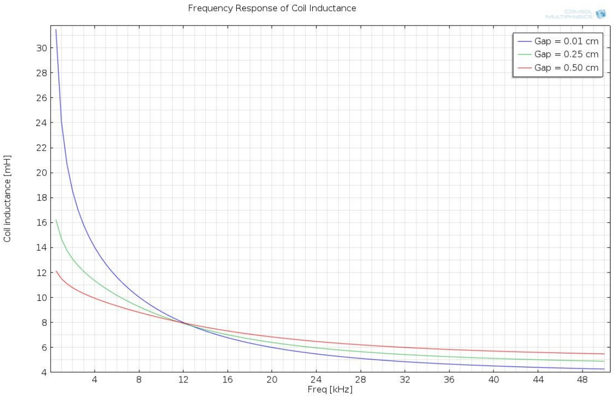

Figure 2: Frequency response of coil inductance.

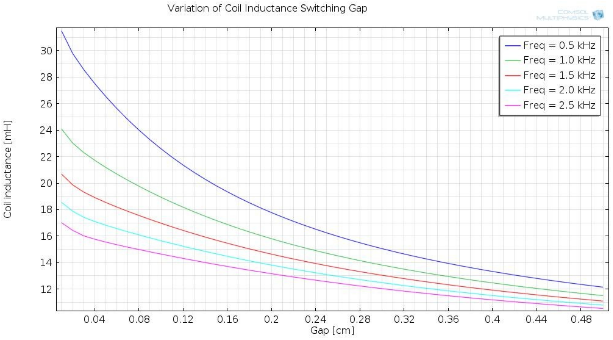

Figure 3: Variation of coil inductance switching gap.