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

K. Z. Gomes[1], T. A. G. Tolosa[1], E. V. S. Pouzada[1]
Mauá Institute of Technology, São Caetano do Sul, SP, Brazil

Abstract: In this work, a methodology is developed, based on the application of finite element method in the frequency domain, aiming the sensibility analysis of inductance calculation involving some configurations of an E-core magnetic circuit. Such important analysis, are made from several geometries and considering different frequencies for the source current applied, providing enough information to study magnetic phenomena, intrinsic problems, 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.

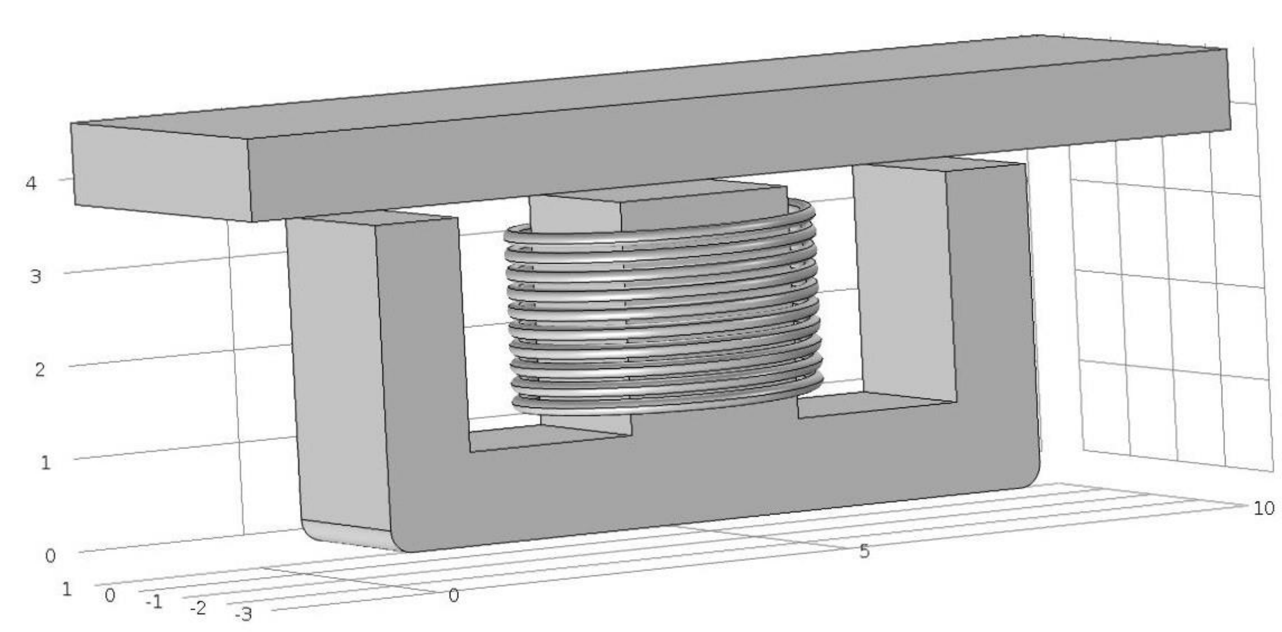

Figure 1. Geometry of inductive sensor.

Computational Methods:
The problem of electromagnetic analysis at a macroscopic level is that of solving Maxwell's equations subject to certain boundary conditions. Maxwell's equations are a set of equations, written in differential or integral form, stating the relationships between the fundamental electromagnetic quantities.
The equations can be formulated in differential form or integral form. The differential form is presented here because it leads to differential equations that the finite element method can handle.
The use of auxiliary vector potentials helps to obtain solutions for the electric and magnetic fields is a common practice in the analysis of electromagnetic boundary-value problems. Considering a linear, homogeneous and isotropic medium, and by the definition of the magnetic vector potential $\vec{A}(t)$, a basic equation can be written:

$$\vec{\nabla} \times \vec{E} + \frac{\partial \left(\vec{\nabla} \times \vec{A} \right)}{\partial t} = \vec{\nabla} \times \left[\vec{E} + \frac{\partial \vec{A}}{\partial t} \right] = 0 \quad (1)$$

Then, assuming a scalar potential Φ,

$$\vec{E} + \frac{\partial \vec{A}}{\partial t} = -\vec{\nabla}\Phi \quad (2)$$

From equation (2), the current density $\vec{J}(t)$ in a conductor region with conductivity σ, excited by a given electric field $\vec{E}_0 = -\vec{\nabla}\Phi$, can be calculated by

$$\vec{J}(t) = -\sigma \cdot \frac{\partial \vec{A}(t)}{\partial t} + \sigma \cdot \vec{E}_0(t) \quad (3)$$

In the case of conductive media, where the displacement current can be neglected, the magnetic vector potential, imposing $\vec{\nabla} \cdot \vec{A} = 0$, relates to the current density by

$$\nabla^2 \vec{A} = -\mu \vec{J} \quad (4)$$

Equation (4) shows that $\vec{A}(t)$ is defined by an integral of the current distribution, so that equation (3) takes the form of an integral equation on $\vec{J}(t)$.

Simulations Results:
The Foucault losses are evident in time dependent problems. The effect of these losses worsens with increasing frequency, because the induced voltage in a system susceptible to time-varying fields is proportional to the derivative of the magnetic flux. Therefore, materials with high electrical conductivity reduce the apparent resistance of the target conductor. In order to verify the distribution of Foucault losses, it was imposed to the proposed system a frequency of 10 kHz and a distance gap that is fixed near to zero.

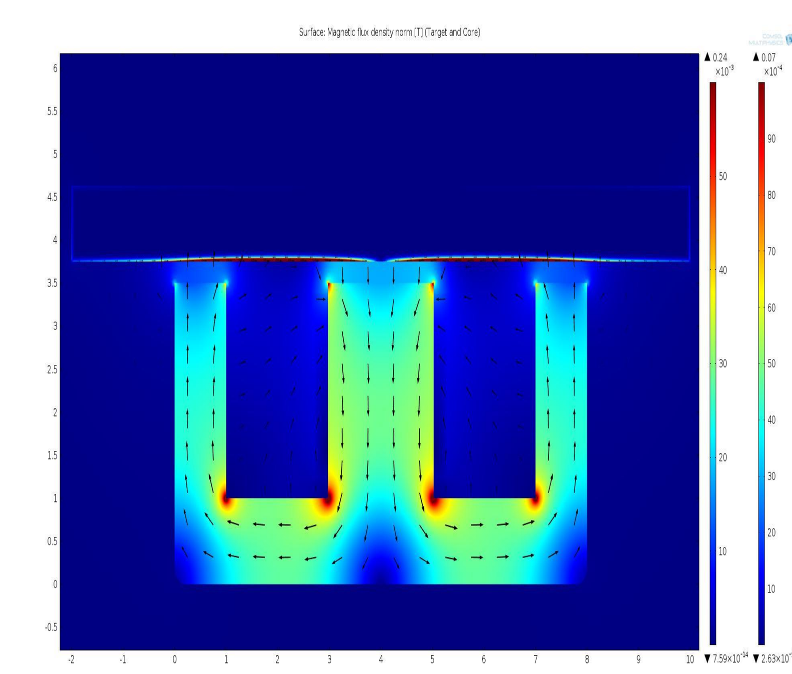

Figure 2. Surface magnetic flux density.

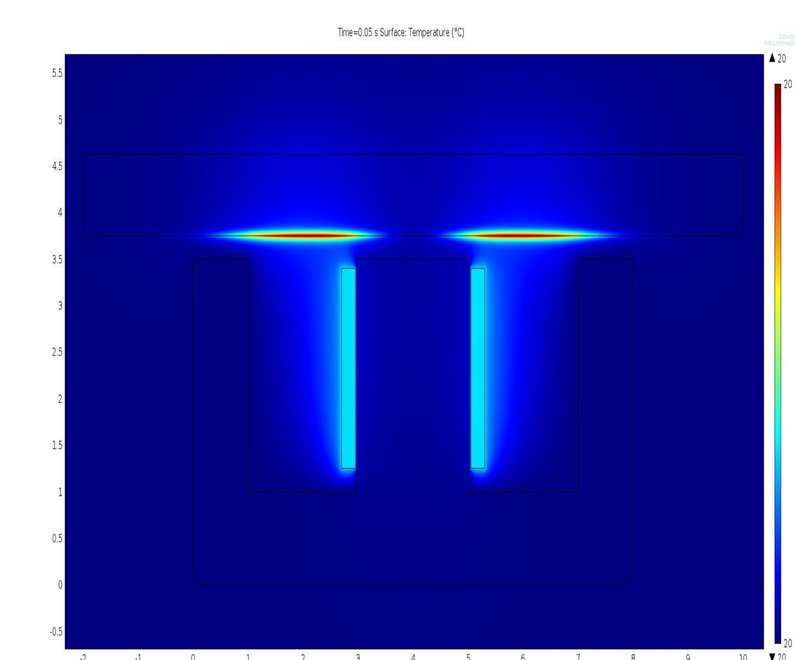

Figure 3. Temperature distribution in the system due two sources of heat: induced currents and the coil.

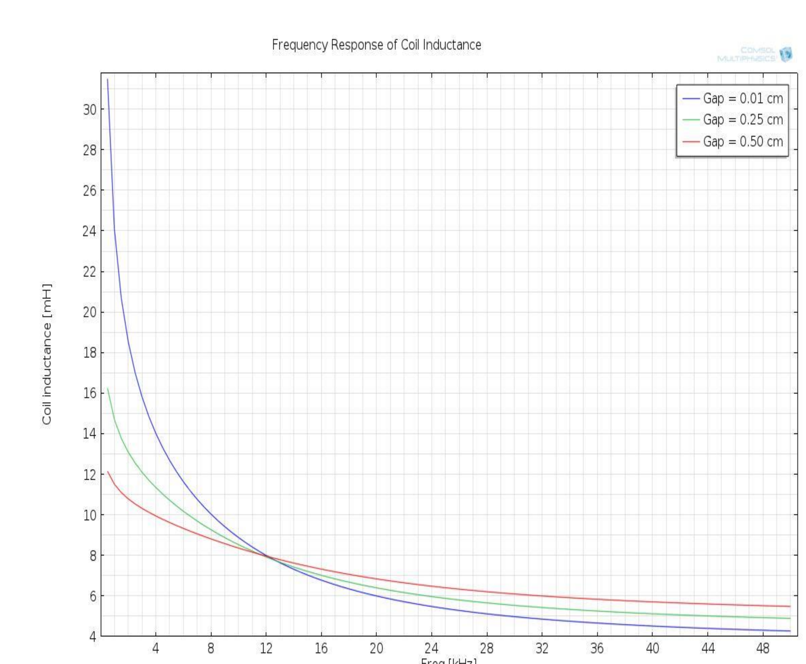

Figure 4. Coil inductance versus frequency for some gaps of study.

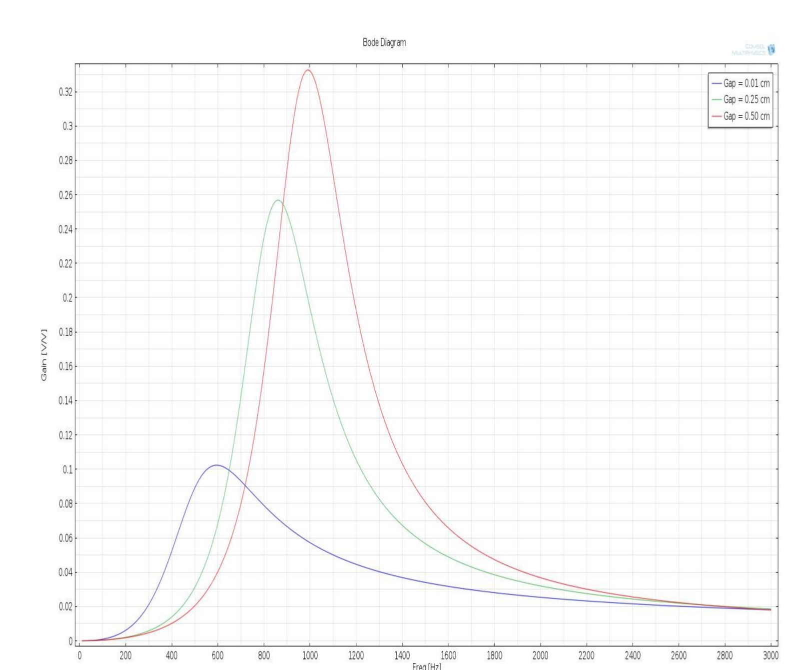

Figure 5. Bode diagram of the band pass filter for some gaps of study.

Conclusions:
The paper has presented an efficient procedure for frequency domain analysis of inductance calculation and such sensibility analysis in the case of non-homogeneous media through the application of FEM.
Some particular configurations of an E-core magnetic circuit were analyzed and the results for the inductance calculation have shown the effects of the problem geometry, material parameters and the way currents flow on the coil.
For the application of the method it is important to take into account the corresponding stability condition that was not analyzed in this paper and can be shown in a future work.
The proposed method can be improved by application of techniques for better performance of the Method and tools for reducing the computational effort by scaling the values of the elements generated in the mesh.

References:
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