Harmonic and Transient Magnetic analysis of Single Turn Coils fed by a Current Pulse at Medium Frequency

O. MALOBERTI[1], O. MANSOURI[1], D. JOUAFFRE[2], D. HAYE[2]

1. ESIEE Amiens, Research, 14 quai de la Somme, 80080, Amiens, France; , [2]PFT Innovaltech

Introduction

Single turn coils are used in pulsed magnetic technologies for which both magneto-harmonic and transient magnetic analysis are required. We study one single turn coil example made of a conducting massive coil and an internal conducting tube to act on. The aim of this study is to evaluate the accuracy and reliability of a 2D axi-symmetrical numerical model by comparing with 3D calculations (see Figure 1).

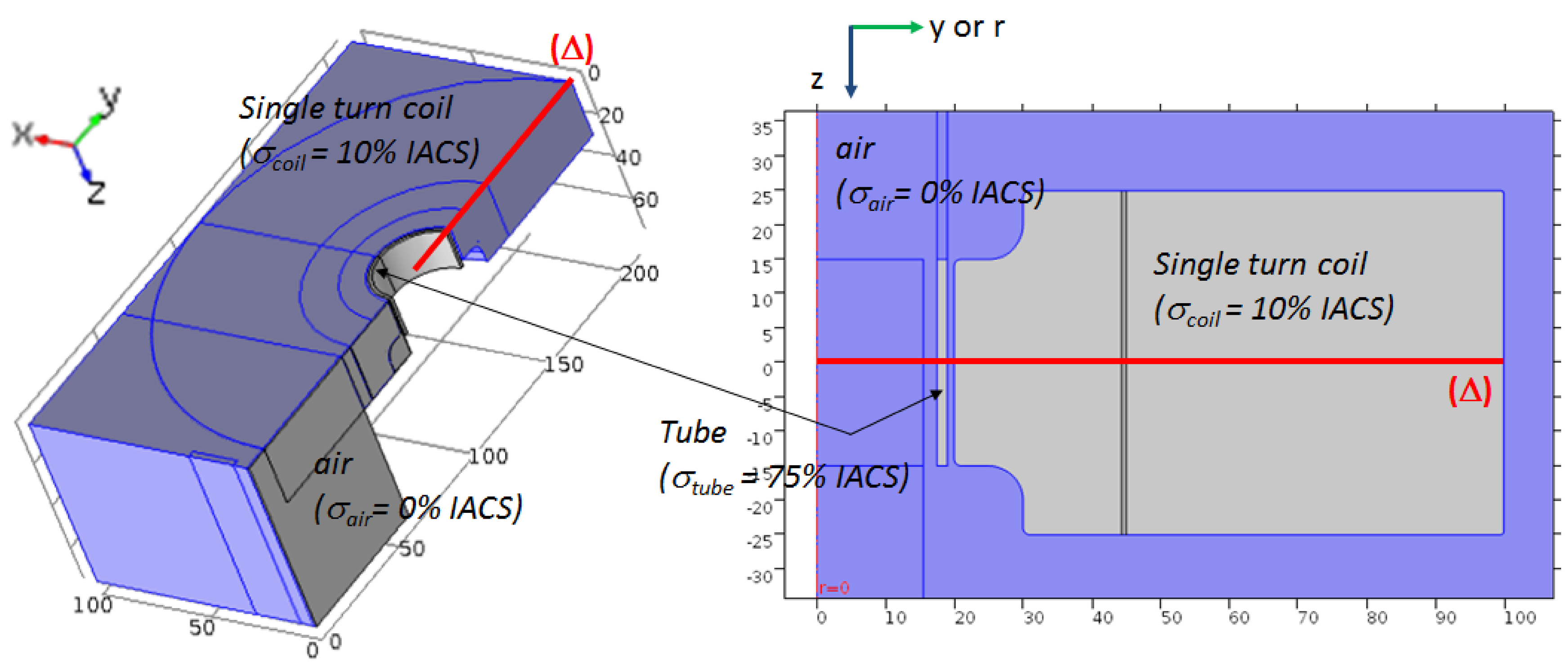

Figure 1. 3D and 2D Geometry.

Computational Methods

The model is computed with the magnetic field formulation, for both harmonic and transient states. The partial differential equation to solve is as follow:

$$\begin{Bmatrix} \nabla \times \nu \nabla \times \mathbf{A} + \sigma \partial_t \mathbf{A} = \mathbf{j_s} \\ \nabla \cdot \mathbf{A} = 0 \end{Bmatrix}$$

A is the magnetic vector potential and $\mathbf{j_s}$ is the current source density
σ is the electrical conductivity (σ_{coil} = 10% IACS, σ_{tube} = 75% IACS, σ_{air} = 0)
ν is the magnetic reluctivity ($\nu = \nu_0 = (1/(4\pi)).10^7$ $H^{-1}m^{-1}$)

The geometry is reduced to ¼ in 3D and can be modeled thanks to an equivalent 2D axi-symmetrical coil. The total current source $I(t)=Ie^{i\omega t}$ injected in the coil is enforced at its terminals. The planes (x,y) and (y,z) are π+ and π- symmetry planes respectively (see Figure 2).

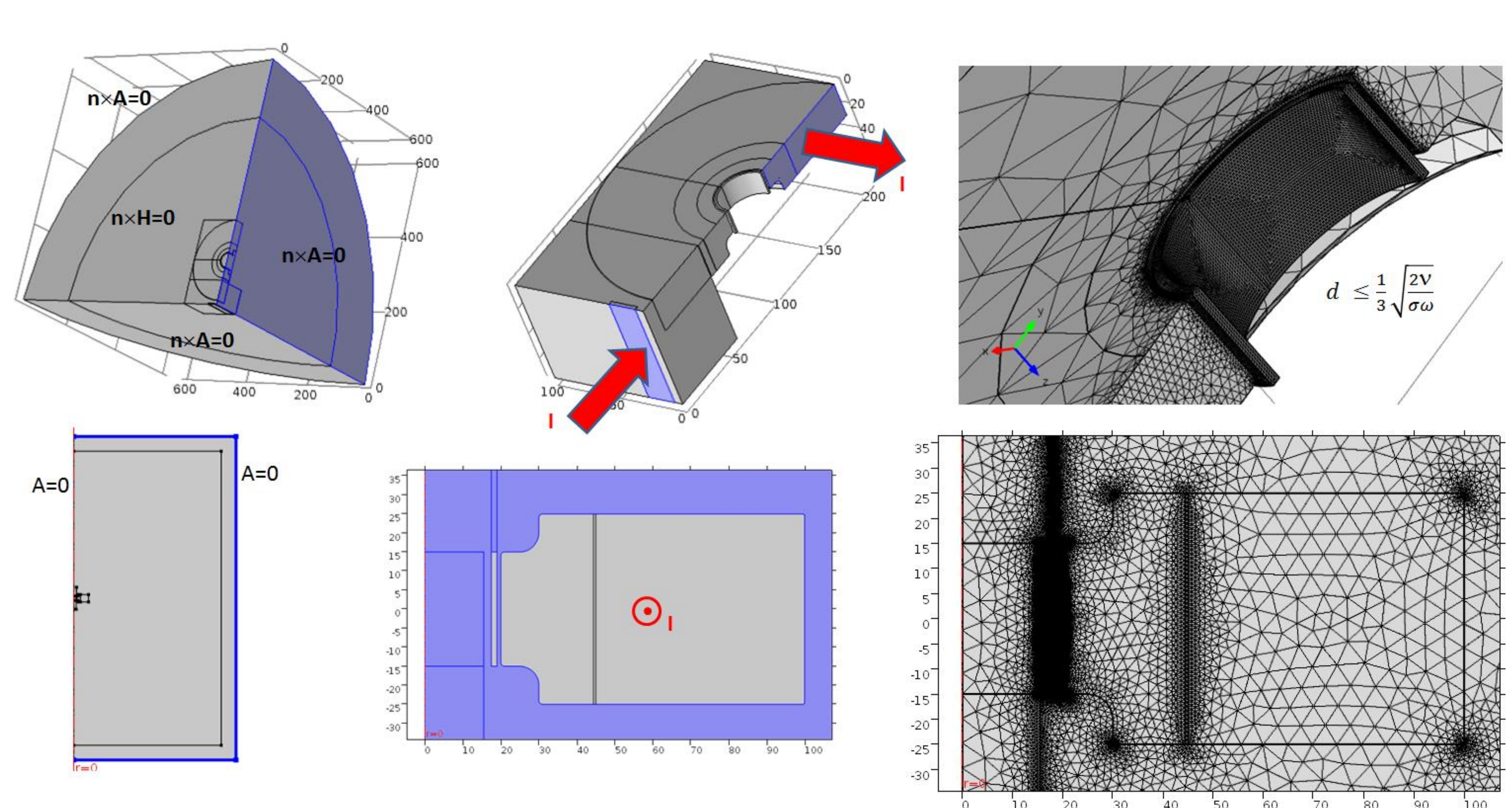

Figure 2. Mesh, Current constraint and Boundary conditions.

Results

With both conditions, we can draw the flux $\mathbf{B}=\nabla\times\mathbf{A}$, current $\mathbf{j}=\mathbf{j_s}-\sigma\partial_t\mathbf{A}$ and radial force density $\mathbf{f}=\mathbf{j}\times\mathbf{B}$ magnitudes (Figures 3-6). As expected, the 3D and 2D results are very close (Figures 3-5). We can also extract the coil resistance R, inductance L and force coefficient K (Figure 7); and finally the transient relationship between the voltage V(t), the current I(t) and the maximum force density F(t) (Figure 6 and 8).

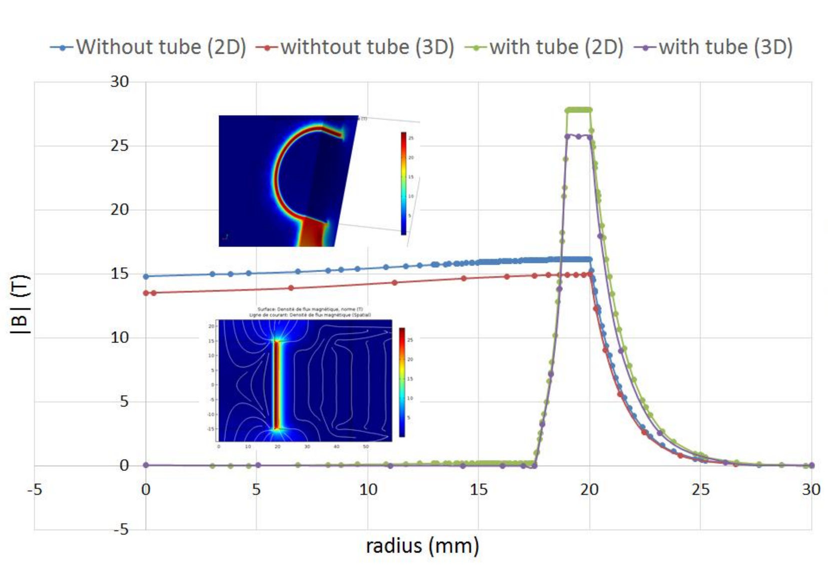

Figure 3. |B|(r) along (Δ) @I=825kA@$\omega/2\pi$=20kHz.

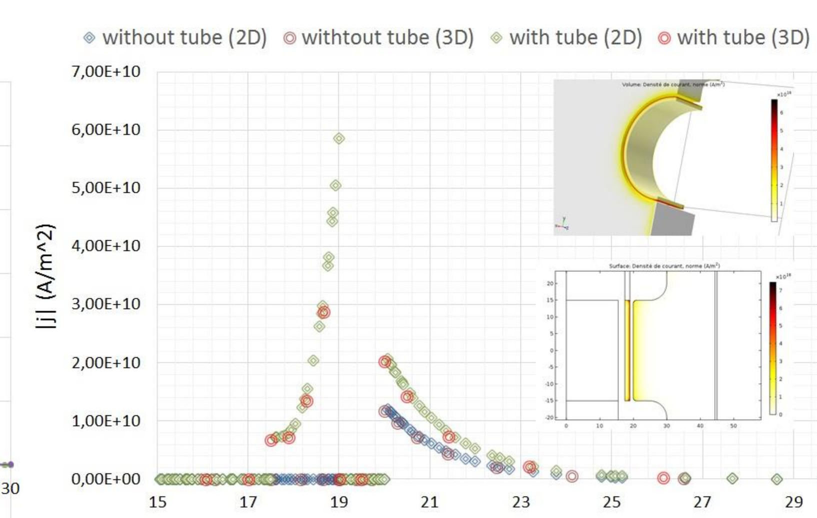

Figure 4. |j|(r) along (Δ) @I=825kA@$\omega/2\pi$=20kHz.

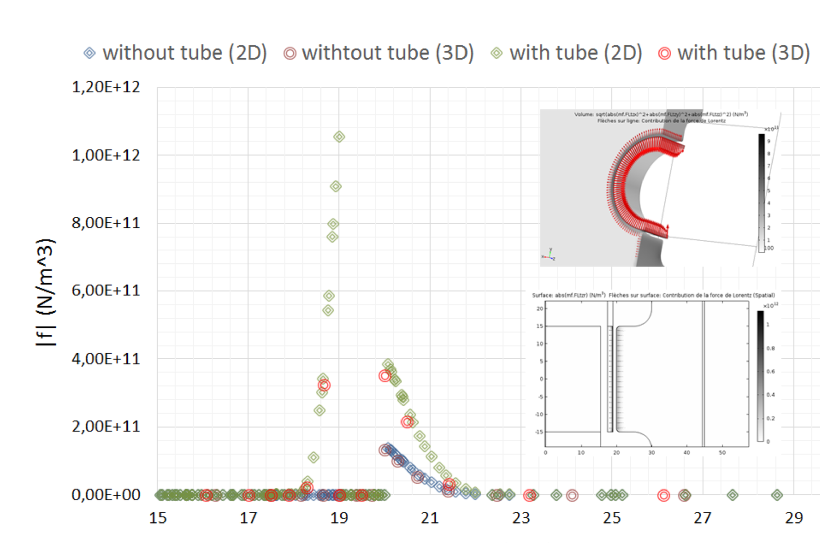

Figure 5. |f|(r) along (Δ) @I=825kA@$\omega/2\pi$=20kHz.

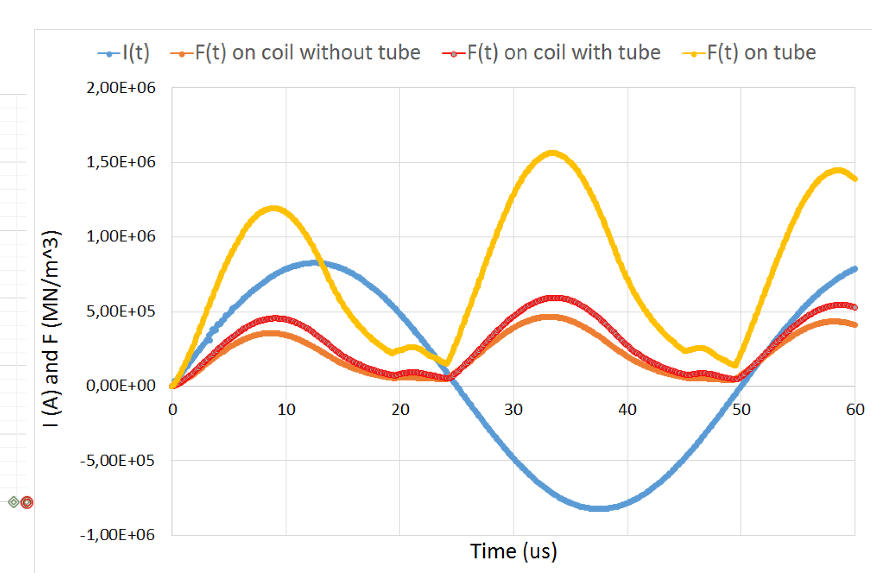

Figure 6. I(t) & F(t) $\propto$ K·I(t)^2 @I=825kA@ $\omega/2\pi$=20kHz.

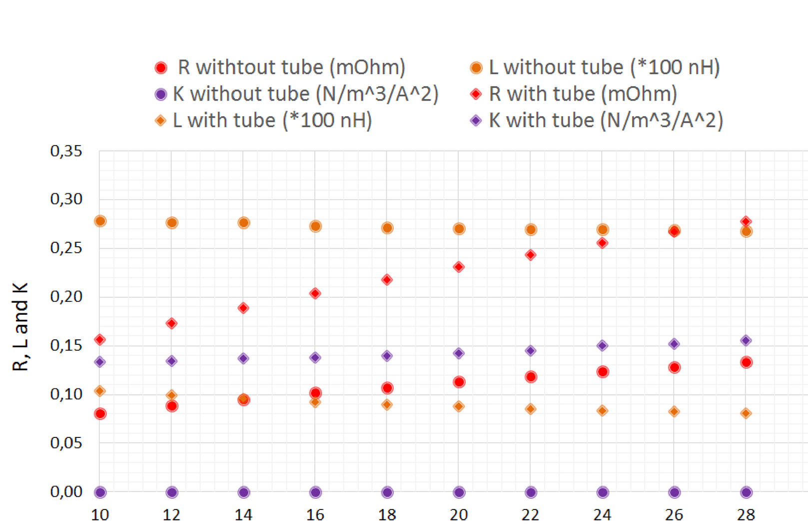

Figure 7. R, L and K *v.s.* ω.

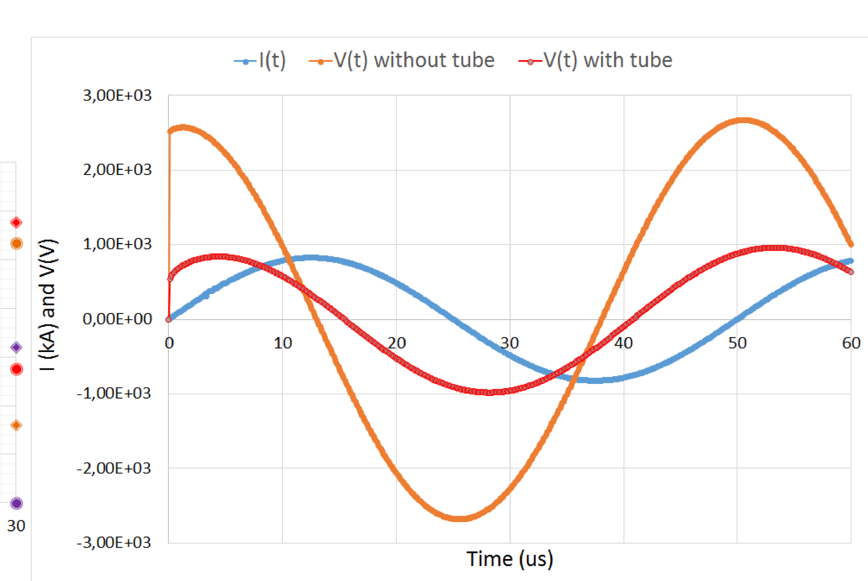

Figure 8. I(t), V(t) behaviours.

Conclusions

The single turn coil with a cut can be modelled thanks to an equivalent 2D axi-symmetrical model. It will then be developed and coupled to the electrical circuit and mechanical deformations.

References:
1. G. Bartels & al, *Int. J. Mater. Form.*, **Vol. 2**, pages 693-696 (2009)
2. M. W. Kennedy & al, *COMSOL Conference in Stuttgart*, (2011)

Excerpt from the Proceedings of the 2015 COMSOL Conference in Grenoble