Harmonic and Transient Magnetic Analysis of Flat Multi-Turn Spiral Coils Fed by a Current Pulse at Medium Frequency

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Introduction

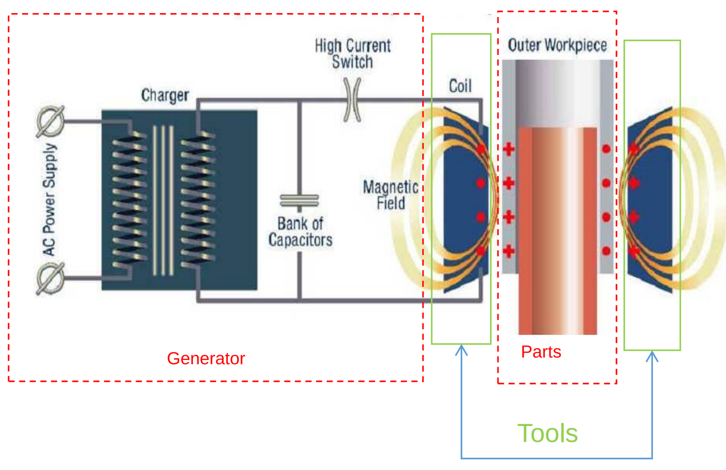

Figure 1. electromagnetic forming technologies.

Multi-turn coils are used in pulsed magnetic technologies for which magneto-harmonic and transient magnetic analysis are required. We study one flat multi-turn spiral coil made of bulk copper alloy with N=8 turns acting on a disk plate of thickness 0.8 mm (see Figure 2).

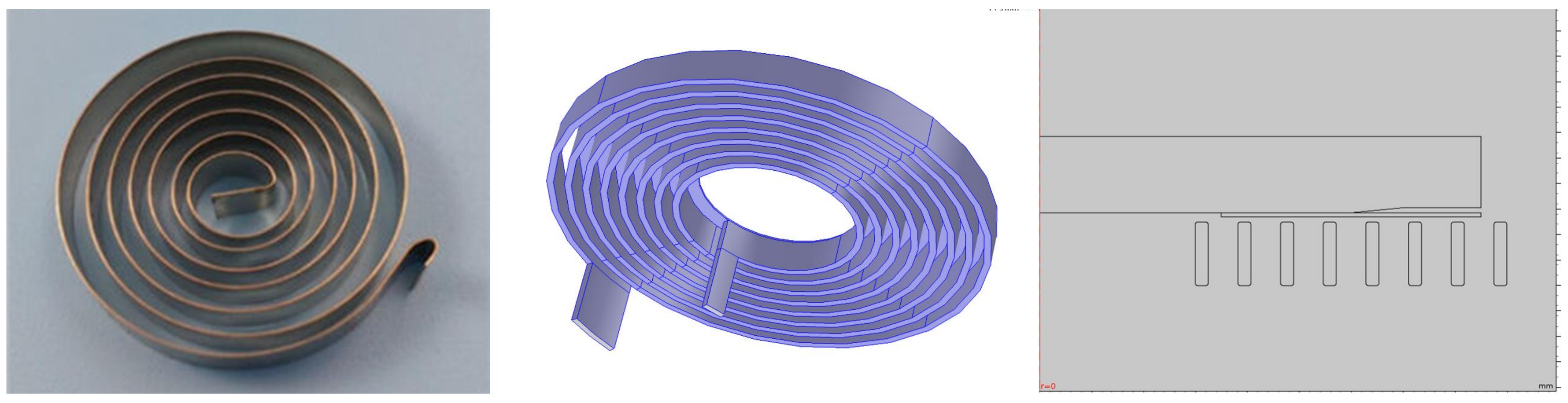

Figure 2. 3D and 2D Geometry.

The 2D axi-symmetrical numerical model (see [1] and Figure 3) provides us a very good approximation of 3D calculations and a reference to test the accuracy and reliability of an equivalent analytical solution [2].

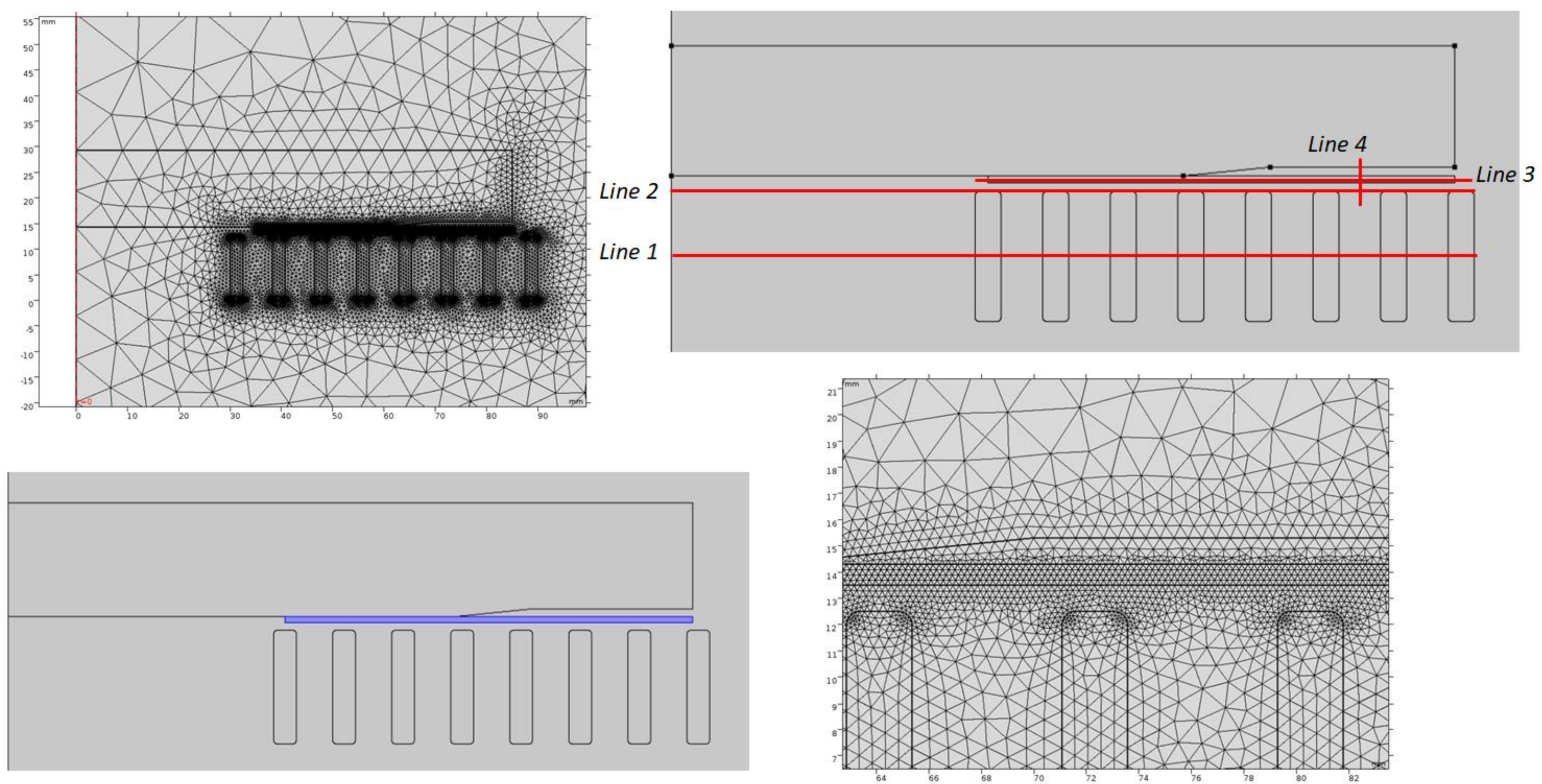

Figure 3. post-processing lines and mesh

Governing equations

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

$$\nabla \times \nu \nabla \times \mathbf{A} + \sigma \partial_t \mathbf{A} = \mathbf{j_s}$$

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} = 70% IACS, σ_{air} = 0)
ν is the magnetic reluctivity ($\nu = \nu_0 = (1/(4\pi)).10^7\ H^{-1}m^{-1}$)

The 3D geometry of a spiral coil can be approximated and modeled thanks to an equivalent 2D axy-symmetrical coil. The total current source $I(t)=Ie^{i\omega t}$ injected in the coil is enforced at the coil's main terminals. The planes (x,y) and (y,z) are π^+ and π^- symmetry planes respectively (see Figure 2)

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 3-8). It is then possible to extract the coil resistance R, inductance L and force coefficient K; and finally the transient relationship between the voltage V(t), the current I(t) and the maximum force density F(t)=max(f(t)) (Z = thickness of each turn).

$$P_j = \iiint_{space} \frac{j^2}{2\sigma} d^3x \text{ and } R = \frac{2P_j}{I^2} \text{ with } I = \iint_{coil} \mathbf{j}\cdot\mathbf{d^2x}$$

$$W_m = \iiint_{space} \frac{B^2}{2\mu} d^3x \text{ and } L = \frac{2W_m}{I^2}$$

$$K_f = \frac{\max(f)}{\sqrt{\omega}\left(\frac{I}{Z}\right)^2}$$

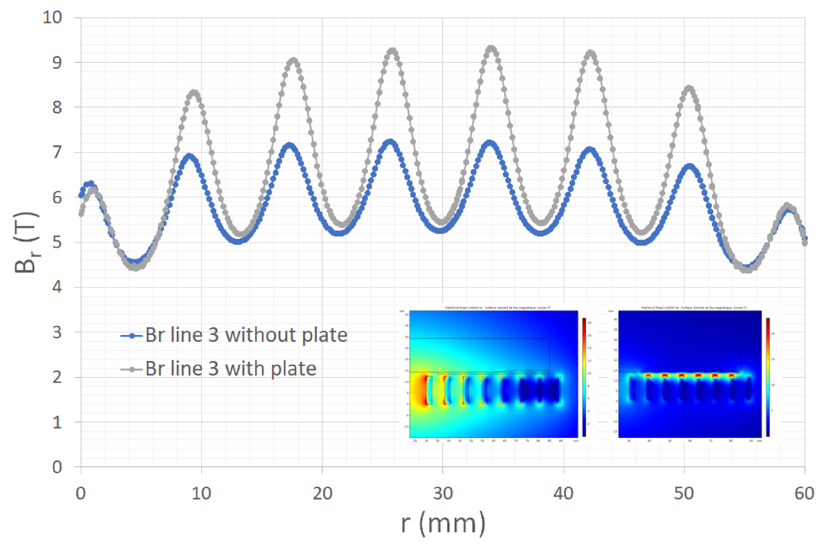

Figure 4. $|B_r|(r)$ line 3 @I=100kA@$\omega/2\pi$=20kHz.

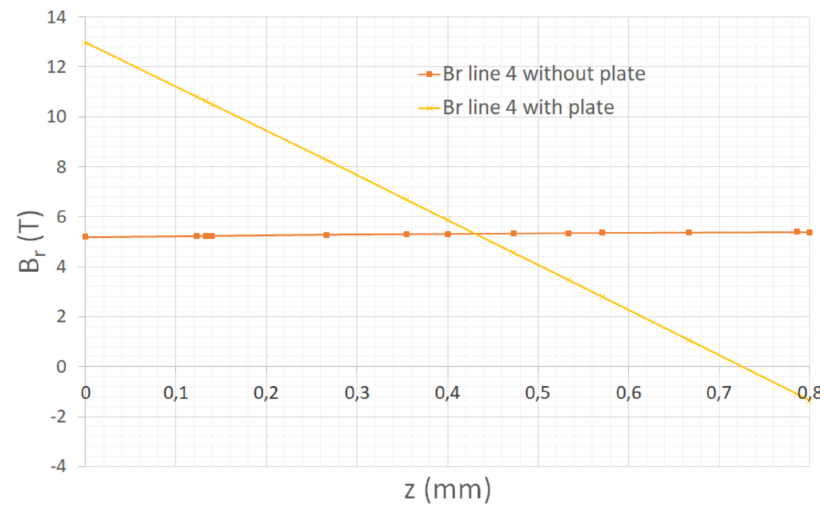

Figure 5. $|B_r|(r)$ line 4 in the disk @I=100kA@$\omega/2\pi$=20kHz.

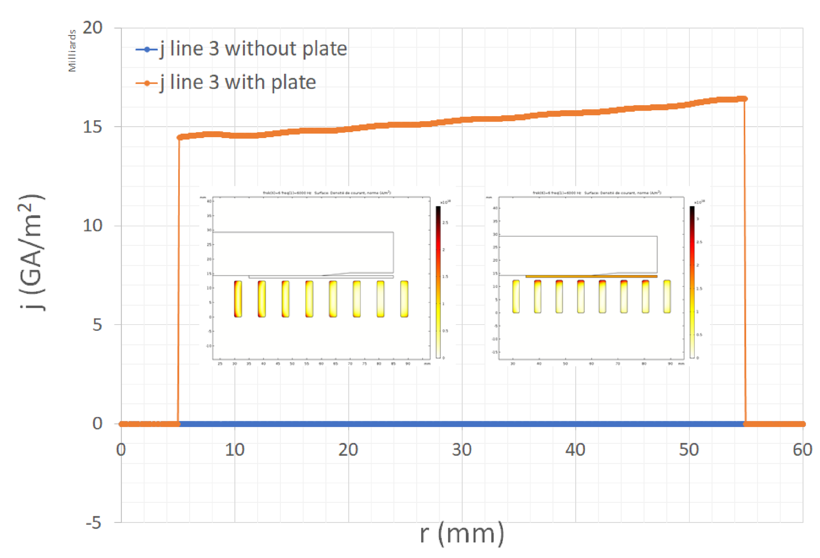

Figure 6. $|j|(r)$ line 3 @I=100kA@$\omega/2\pi$=20kHz.

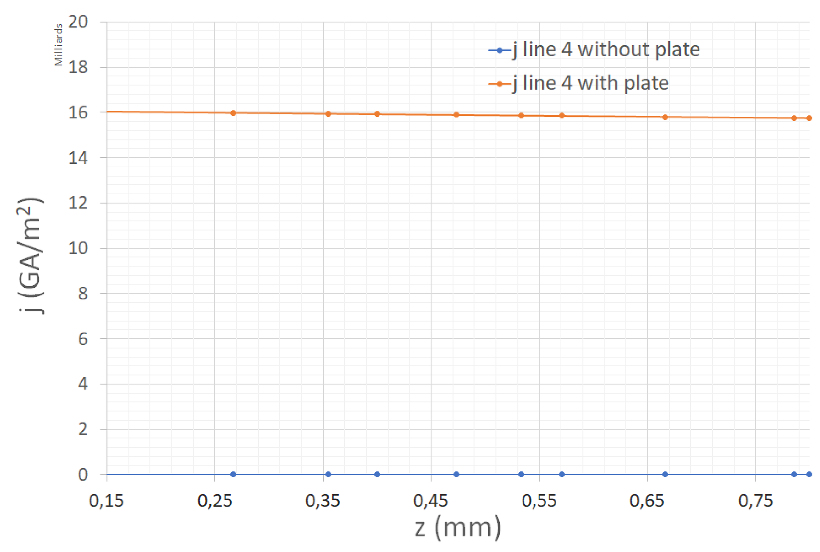

Figure 7. $|j|(r)$ line 4 in the disk @I=100kA@$\omega/2\pi$=20kHz.

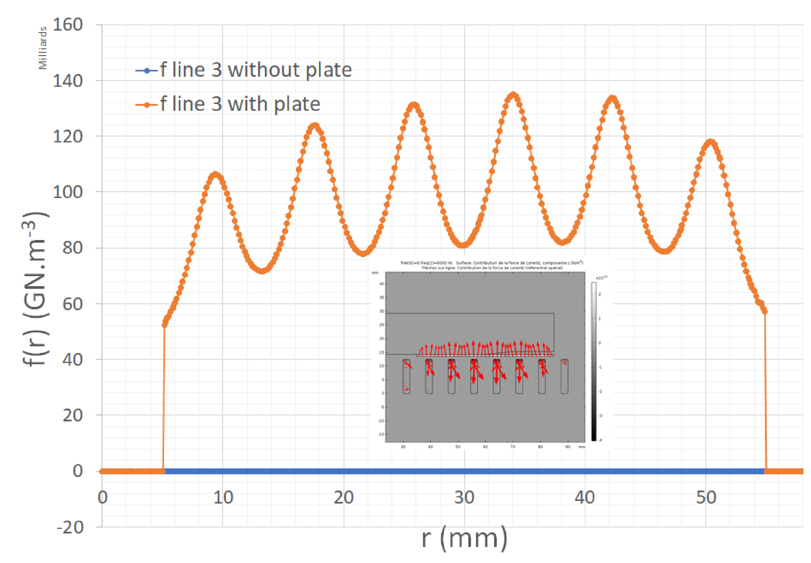

Figure 8. $|f|(r)$ line 3 @I=100kA@$\omega/2\pi$=20kHz.

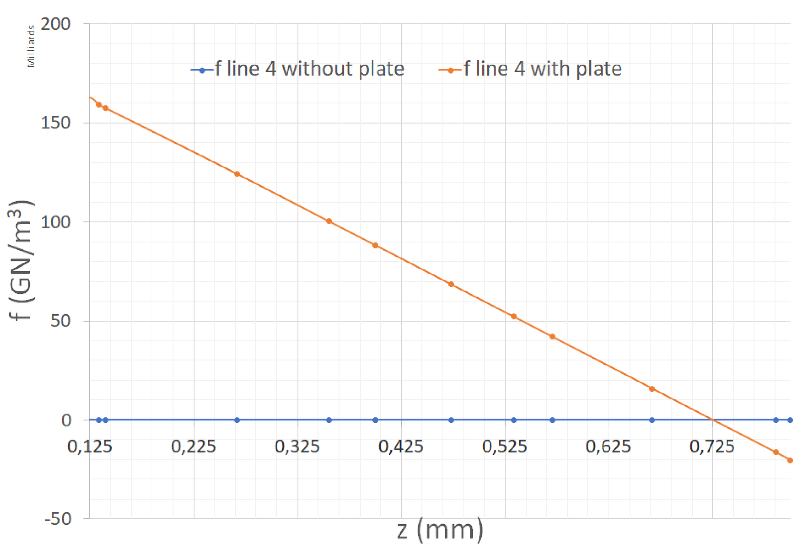

Figure 9. $|f|(r)$ line 4 in the disk @I=100kA@$\omega/2\pi$=20kHz.

Conclusions

The flat multi-turns spiral coil has been computed thanks to an equivalent 2D axi-symmetrical model. It will then be developed and coupled to the electrical circuit and mechanical deformations.

References:
[1] E. Paese, PhD, Porto Alegre, Janeiro (2010)
[2] J. Bednarczyk & al, *ICCC Conference in Malenovice*, (2002)