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

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Introduction

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).

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].

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:

$$\nabla \times \nabla \times \mathbf{A} + \sigma \frac{\partial \mathbf{A}}{\partial t} = \mathbf{j}_s$$

$\mathbf{A}$ is the magnetic vector potential and $\mathbf{j}_s$ is the current source density.

$\sigma$ is the electrical conductivity ($\sigma_{\text{coil}} = 10\%$ IACS, $\sigma_{\text{tube}} = 70\%$ IACS, $\sigma_{\text{air}} = 0$)

$\nu$ is the magnetic reluctivity ($\nu = \nu_0 = (1/(4\pi)) \cdot 10^7 \text{H/m}^{-1}$)

The 3D geometry of a spiral coil can be approximated and modeled thanks to an equivalent 2D axi-symmetrical coil. The total current source $I(t) = I_0 \cdot \text{sin}(\omega t)$ injected in the coil is enforced at the coil’s main terminals. The planes (x,y) and (y,z) are $\pi^*$ and $\pi^-$ symmetry planes respectively (see Figure 2).

Results

With both conditions, we can draw the flux $B = \nabla \times \mathbf{A}$, current $j = \mathbf{j}_s - \sigma \frac{\partial \mathbf{A}}{\partial t}$ and radial force density $f = j \times B$ 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 $F(t) = \text{max}(f(t))$ ($Z$ is thickness of each turn).

$$R = \int \frac{1}{2\mu} d^2 x$$

$$W_m = \int \frac{1}{2\mu} B^2 d^2 x$$

$$K_r = \text{max}(f) \sqrt{\frac{\omega}{2}}$$

Conclusions

The flat multi-turn 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: