Magneto-Mechanical-Thermal Couplings for the Pulsed Magnetic Technology with Single-Turn Coils

O. Maloberti[1], P. Sansen[1], D. Jouaffre[2], D. Haye[2]

[1]ESIEE Amiens, France
[2]PFT Innovaltech, France

Abstract

Single turn coils produce AC and transient magnetic fields in pulsed magnetic technologies for which magneto-harmonic and transient magnetic analysis can be primarily performed. We suggest studying one single turn coil example made of a conducting massive coil, an optional conducting field shaper and an internal conducting tube supposed to be deformed. The pulsed high magnetic field created induce eddy currents in both the field-shaper and the tube. The latter interact with the magnetic field to induce a Lorentz force that tends to deform the field-shaper and compress the tube. Meanwhile, the electrical currents inside the coil, the field-shaper or the tube generate heat losses and the temperature might increase during the process. Therefore, couplings between the magnetics and the mechanics on one side and between the magnetics and the thermal effects on the other side are required. The complete electromagnetic and electrical analysis have already been computed and validated with the AC and transient magnetic field mode with COMSOL Multiphysics® in [1]. The aim of this study is to evaluate the feasibility, accuracy and reliability of a 2D axi-symetrical numerical model by comparing with reference like measurements or 3D calculations in order then to build an approximate but reliable analytical solution that might ease the coupling with electrical, mechanical and thermal physics.
In this work we propose to:
- First introduce the 2D axi-symetrical geometry and the initial electromagnetic model in COMSOL (sources, materials, limit conditions and mesh)
- Then introduce and perform transient mechanical and magneto-mechanical computations:
o Definition of the mechanical model (sources, materials, limit conditions and mesh)
o Governing coupled electromagnetic and mechanical equations
o Draw the Lorentz force density, stress and deformation profiles
o Analysis of the relationship between the current, the maximum force, elastic stress and deformation as a function of time
o Yield stress threshold and deformability analysis
- Finally introduce and perform thermal and magneto-thermal computations:
o Definition of the thermal model (sources, materials, limit conditions and mesh)
o Governing coupled electromagnetic and thermal equations
o Draw the heat source, flux and temperature profiles
o Extract some needed information on the coil, such as the equivalent heat capacity, thermal resistance and time constant

o Production rate limitation and productivity analysis
- Methodology to estimate the lifetime

References
[1] O. Maloberti, O. Mansouri, D. Jouaffre, D. Haye, "Harmonic and Transient Magnetic analysis of Single Turn Coils fed by a Current Pulse at Medium Frequency", COMSOL Conference 2015, 14-16 october 2015, Grenoble.
[2] Ph. Conraux et al., "3D Finite Element Modeling of Electromagnetic Forming Processes", 2nd International Conference on High Speed Forming - 2006, pp. 73-82.
[3] Alle Navee Kumar et al., "Finite Element Modeling and Simulation of Electromagnetic Forces in Electromagnetic Forming Processes: Case Studies using COMSOL Multiphysics", Proceedings of the COMSOL Conference 2009 Bangalore.
[4] S. Pasca, T. Vesselenyi, V. Fireteanu, "Transient Phenomena in Electromagnetic Forming Processes", International Scientific Colloquium Modeling for Electromagnetic Processing Hannover, October 27-29, 2008.
[5] Angshuman Kapil and Abhay Sharma, "Coupled Electromagnetic-Structural Simulation of Magnetic Pulse Welding", Advances in Material Forming and Joining, pp. 255-272.
[6] Pierre L'Eplattenier, Grant Cook, Cleve Ashcraft, Mike Burger, Art Shapiro, "Introduction to an Electromagnetism Module in LS-DYNA for Coupled Mechanical-Thermal Electromagnetic Simulations", 9th LS-DYNA users' conference, 2006.
[7] Khadija Sofi et al., "Current and temperature distribution in a massive one turn coil used in electromagnetic pulse generator", 18th International Symposium on Electromagnetic Fields in Mechatronics, Electrical and Electronic Engineering (ISEF) Book of Abstracts, 2017.

Figures used in the abstract

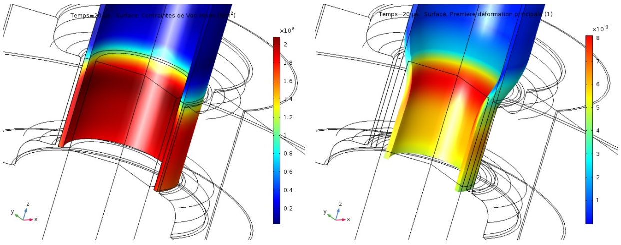

Figure 1: Peak compression Von Mises stress (left) and main strain (right) due to Lorentz force.