FLUX Version 8.1: 3D Magnetothermal.

Bernard Paya - EDF, Virgiliu Fireteanu, Alexandru Spahiu - Bucharest Politehnica University, Christophe Guérin, Marc Vilcot - CEDRAT.

For 10 years, the 2D magneto-thermal modelling has been related to various applications such as:

- Surface treatment
- Induction hardening
- Continuous heating
- Deposit of anti-corrosion materials on pipe-lines
- Tubes welding
- Closing of food boxes
- Preparation of your favorite meals (induction plates)

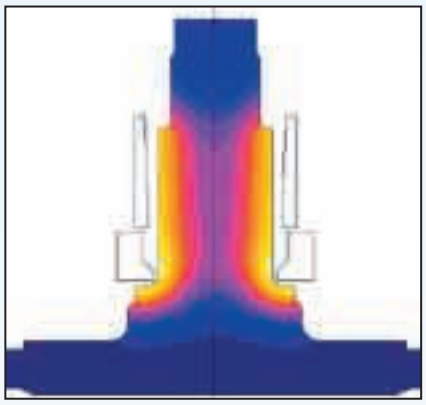

Figure 1: Induction hardening: distribution of the temperature and hardened profile. Acknowledgements : ***www.magnetic.it.***

The model used in is not restrained only to the exportation of dissipated power computed in magnetic module towards the thermal one. The magneto-thermal coupling actually implements a real interaction between the magnetic and thermal fields permitting the consideration of temperature variation of:

- Magnetic and electric properties (permeability, resistivity),
- Thermal properties (thermal conductivity, heat capacity),
- Exchange conditions (convection, radiation).

Figure 3: Induction hardening of a crankshaft. Volume density of induced power. Acknowledgments: Prismeca, ***www.prismeca.fr***

The 2D magneto-thermal coupling aficionados, the 3D users of weak coupling (export of powers of the electromagnetic part towards the thermal part) will be from now able to build up a 3D magneto-thermal model. This model offers the same models of thermal dependence of the material properties as the 2D model.

The validations of this new module have been carried out within the collaboration contract frame of FLUX, Electricité de France (Renardières site) and POLITEHNICA University of Bucharest (EPM_NM laboratory: ***www.amotion.pub.ro/~epm***). The validations referred to a significant number of configurations. One of them is presented hereafter, a demanding one as far as the models used for modelisation are concerned.
The problem consists in the induction heating at 45 kHz of a steel tube with a longitudinal slot (see figure 4), the total current of the inductor being 1.2 kA. This geometry is a first representation of a pressure welding of tubes heated by induction. There is a slot of 5 mm on the tube (external diameter 100 mm, thickness 5 mm). An inductor of 2 turns surrounds the tube and a ferrite core is placed inside the tube.
The resistivity of the tube is described by a linear dependence on temperature: $20 \cdot 10^{-8}$ $(1 + 0.004 \cdot \theta)$ Ωm. Its relative permeability is 750 before the Curie point (760° C) and it decreases to the unity around this point. This linear magnetic model, in which the magnetic permeability is independent from the magnetic field, but depends on the temperature, allowed us to use a surface impedance formulation of electromagnetic field in the tube region. This lightened considerably the computation for high skin effects that had to be considered in this case (B. Paya and C. Guérin, "Magnetic field dependence of non linear surface impedance: which field to choose? ", IEEE Trans. Magn. vol 38, no 2, March 2002, pp. 585-588).

The convective exchange coefficient on the surface of the tube was chosen as 20 W/m²/°C. The radiative coefficient is equal to 0.8. Figure 5 shows the position of 5 measurement points on the tube surface (P1 to P5).
A comparison of the 3D simulation results in relationship to the measurements shows coherent results (figure 7).

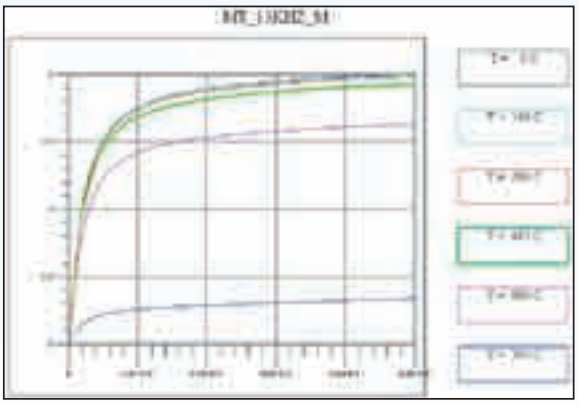

Figure 2: B as function of H and T.

(continued on page 18)

FLUX Version 8.1: 3D Magnetothermal. (continue).

Bernard Paya - EDF, Virgiliu Fireteanu, Alexandru Spahiu - Bucharest Politehnica University, Christophe Guérin, Marc Vilcot - CEDRAT.

However, we can note some differences due to the linearity of the model used in this case.

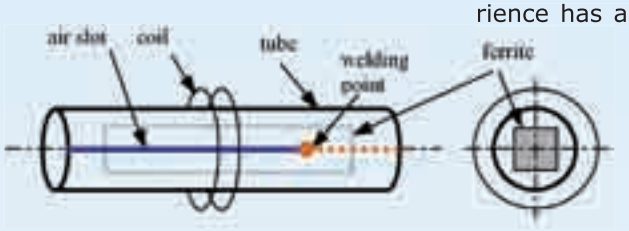

Figure 4: Physical model of HF induction heating.

The use of a volume magnetic non-linear and temperature depending formulation, harder as far as the unknowns are concerned, allows for the consideration of saturations on the slot contours and a better correlation between simulation results and measurements.

This article shows the advances of 3D modeling concerning the coupling between electromagnetic and thermal fields. We would like to express our gratitude to EDF/ Induction Group and EPM_NM/POLITEHNICA University that have contributed to this 3D magneto-thermal application in the V8.1 version of FLUX, and also to the Induction community whose experience has allowed us to progress in the modeling of these phenomena for 15 years.

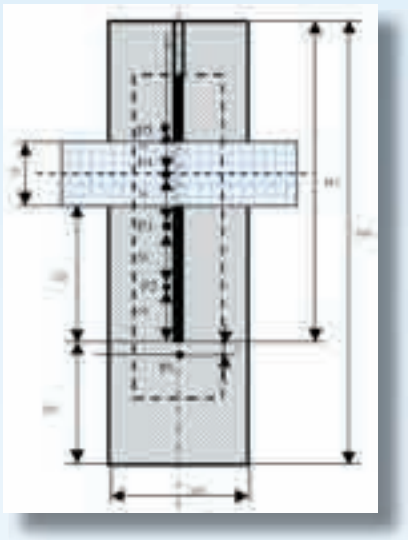

Figure 5: Position of the thermocouples in the HF experiment.

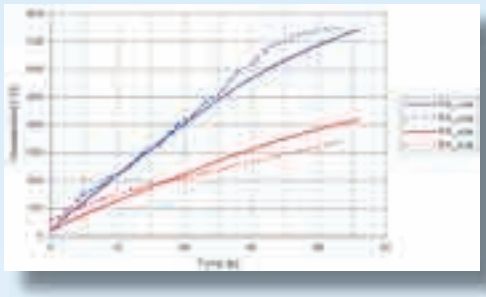

Figure 7: Comparison computations/ measurements.

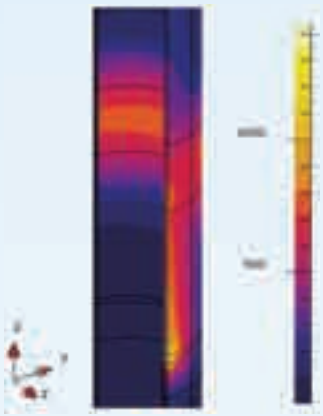

Figure 6: Chart of temperature after 40 seconds HF heating.

FLUX Version 8.1: A flux of innovations.

(continue)

Sébastien Cadeau-Belliard - CEDRAT.

- Improvement of the 3D formulation for the circuit coupling:

This new formulation allows the better modelling of devices with thin air-gap or closed magnetic circuit coupled with an external electric circuit.

But, certainly, as one page is not enough to show all the news, we invite you to contact us in order to attend the «discover Version 8.1» stages (see page 22) and try the new FLUX software !

3D automatic formulations!

For 3D computations, FLUX offers now a new option to determine the formulation to apply: the «AUTOMATIC» option.
As anyone may have guessed, this option enables not to choose the formulation of any volume and surfacic region. It will be automatically determined by FLUX.
Then, during the Magnetostatic, Magnetoharmonic and Transient Magnetic computations, the users have two possibilitites:
- Choose the formulation for every region as before (for nostalgic users)
- Choose the option **"AUTOMATIC"**. FLUX defines itself the formulation to apply.