



Heat Treatment modelling with Flux[®]

Applications for heat treatment

- Applications:

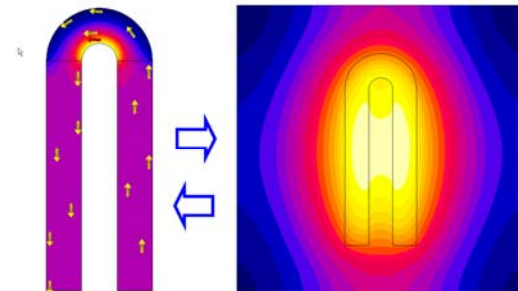
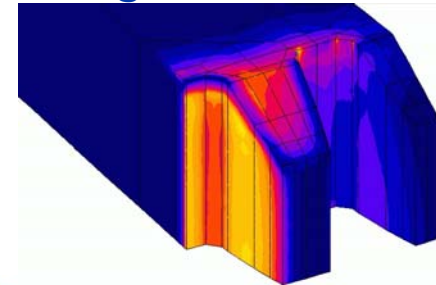
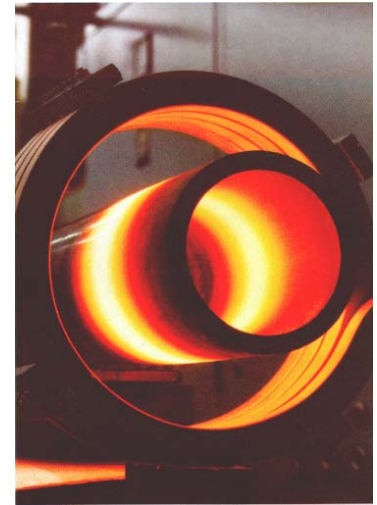
- » Induction Heating
- » Conduction Heating
- » Dielectric heating

- For:

- » Heating, Brazing, Welding, Forging, Hardening, Sealing...

- Involves:

- » Thermal transient calculation coupled with:
 - ✓ Magnetic simulation
 - ✓ Electric conduction simulation
 - ✓ Dielectric simulation



Applications for heat treatment

- Limitless studies:
 - » Design and optimize a heating process
 - » Virtual prototyping of inductors
 - » Study the temperature distribution at any time during the heat treatment process
 - » Compare different process together
 - » Evaluate the materials sensitivity to temperature variations
 - » ...

Applications for heat treatment

Results:

» Thermal quantities:

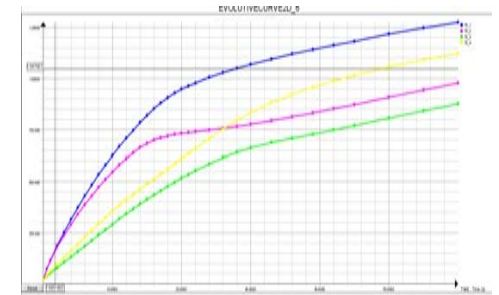
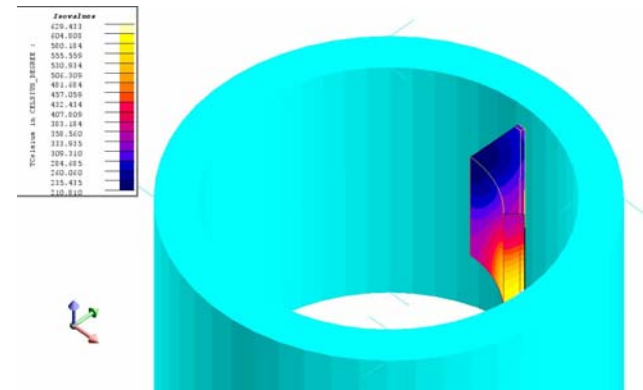
- ✓ Temperature color map distribution
- ✓ Temperature curves versus time
- ✓ Thermal losses

» Electromagnetic quantities:

- ✓ Flux density
- ✓ Currents, joule losses
- ✓ Electromagnetic forces

» Materials properties variation versus time:

- ✓ Permeability
- ✓ Conductivity
- ✓ Thermal Conductivity
- ✓ Specific heat



Benefits of using Flux for heat treatment

- A unique set of coupled applications:
 - » **Magneto-thermal** 2D and 3D (AC magnetics coupled with transient thermals)
 - » Electro-thermal 2D and dielectro-thermal 2D
 - » **Multiphysics features** allowing to couple any FLUX application modules: Conduction 3D and transient thermal or steady-state-thermal,...

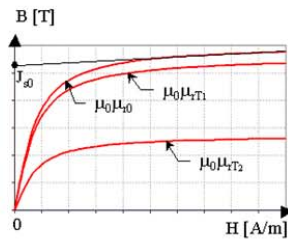
- Allowing to:
 - » Solve in the same loop the magnetic and thermal equations:
 - ✓ Magnetic calculation of Joule losses is automatically taken into account as the source of heating
 - » Take into account material properties variations versus the actual temperature

Benefits of using Flux for heat treatment

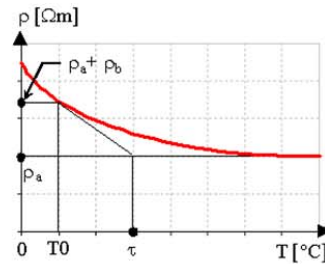
- Material properties models depends on temperature:

Magnetic property
(dependent on temperature)
isotropic soft magnetic material
analytic saturation curve with knee adjustment * exponential function of temperature

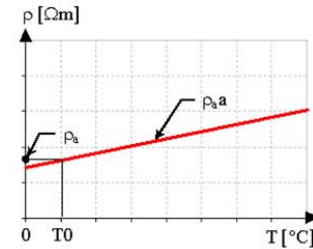
$$B(H) = \mu_0 H + J_{s0} \frac{H_a + 1 - \sqrt{(H_a + 1)^2 - 4H_a(1-a)}}{2(1-a)} \text{COEF}(T)$$

$$H_a = \mu_0 H \frac{\mu_{r0} \text{COEF}(T) - 1}{J_{s0}}$$


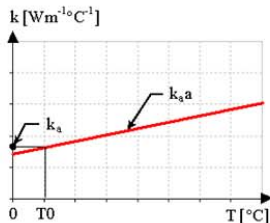
Electrical property
isotropic resistivity, exponential function of T

$$\rho(T) = \rho_a + \rho_b e^{-(T-T_0)/\tau}$$


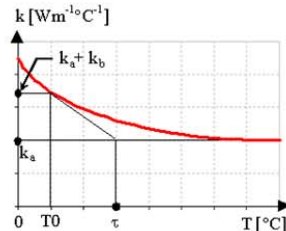
Electrical property
isotropic resistivity, linear function of T

$$\rho(T) = \rho_a (1 + a(T - T_0))$$


Thermal conductivity
isotropic, linear function of T

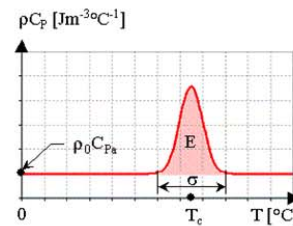
$$k(T) = k_a (1 + a(T - T_0))$$


Thermal conductivity
isotropic, exponential function of T

$$k(T) = k_a + k_b e^{-(T-T_0)/\tau}$$


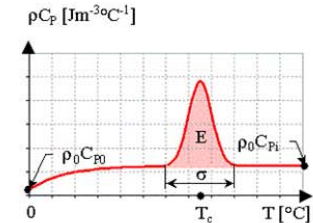
Volumetric heat capacity
constant + Gaussian function of T

$$\rho C_p(T) = \rho C_{p0} + E \cdot \text{Gauss}(T)$$

$$\text{Gauss}(T) = \frac{1}{\sigma \sqrt{2\pi}} e^{-\frac{1}{2} \left(\frac{T - T_c}{\sigma} \right)^2}$$


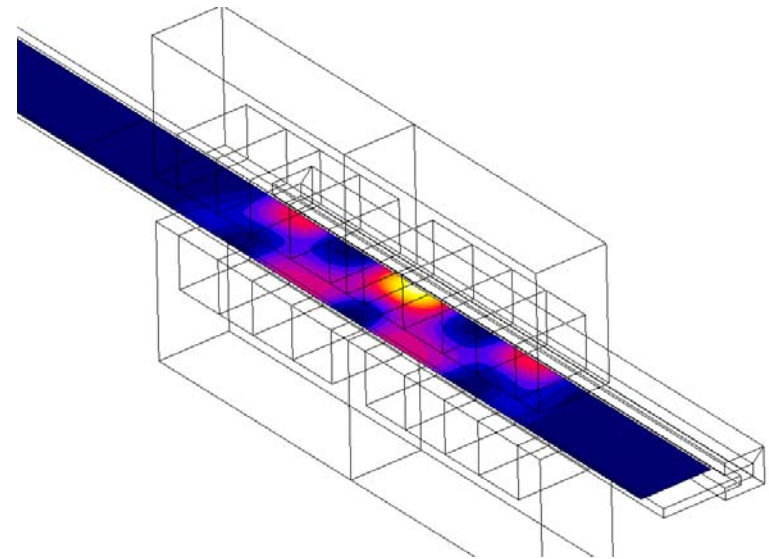
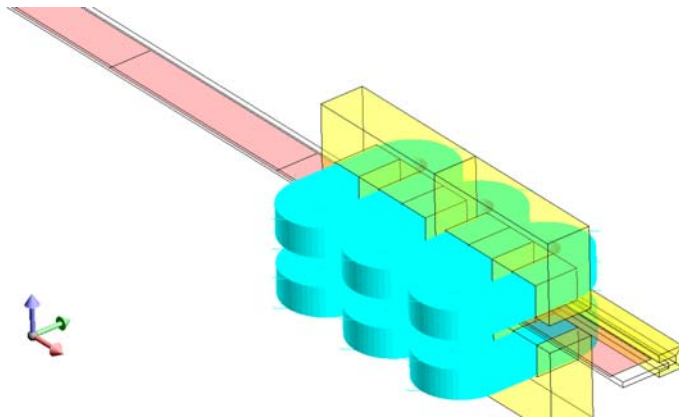
Volumetric heat capacity
exponential function of T + Gaussian function of T

$$\rho C_p(T) = \rho C_{p1} + (\rho C_{p0} - \rho C_{p1}) e^{-T/\tau} + E \cdot \text{Gauss}(T)$$

$$\text{Gauss}(T) = \frac{1}{\sigma \sqrt{2\pi}} e^{-\frac{1}{2} \left(\frac{T - T_c}{\sigma} \right)^2}$$


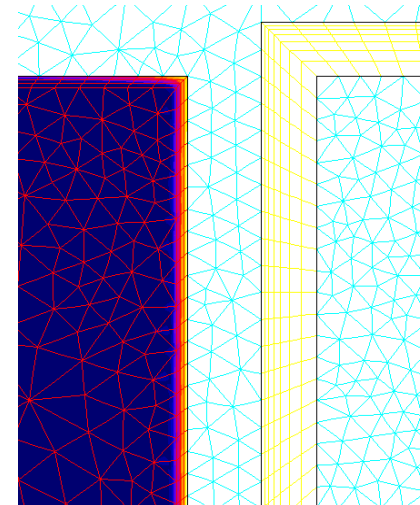
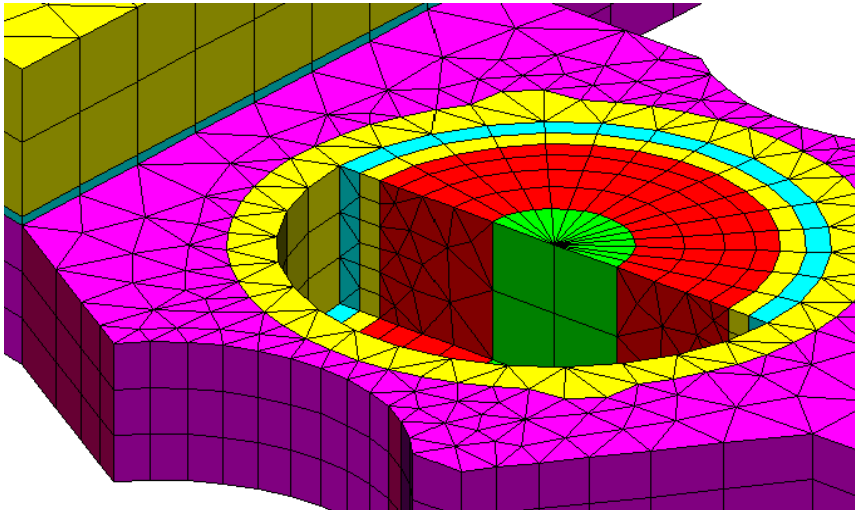
Benefits of using Flux for heat treatment

- A unique model of « thin conductive regions »:
 - » Thin conductors are represented as surface models
 - » No need to mesh the thickness
 - » Simplification of the model with the same accuracy
 - » Dramatic optimization of the calculation time



Benefits of using Flux for heat treatment

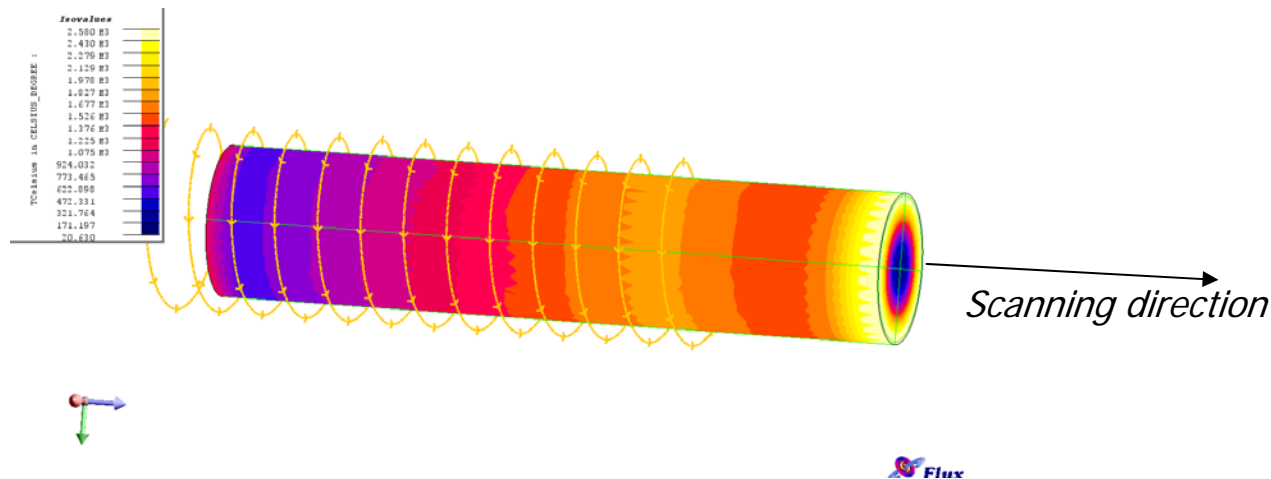
- A unique mixed mesh generator:
 - » Possibility to mix tetrahedrons and mapped mesh in the same model
 - » Mapped mesh allow to
 - ✓ Adapt the mesh to the skin effect
 - ✓ Reduce the mesh size while increasing results quality
 - ✓ Reduce calculation time



Benefits of using Flux for heat treatment

- Kinematic coupling:

- » Allowing to represent scanning heating process
- » Linear or rotational motion



- » Associated to a partial remeshing technique:

- ✓ The moving part mesh remains constant whatever the position: better accuracy
- ✓ The surrounded air is automatically remeshed

Benefits of using Flux for heat treatment

- Electric circuit coupling:
 - » Allowing to define the electrical source of the inductor:

The screenshot displays the Flux 10.2 software interface. The main window shows a circuit diagram with a voltage source, a resistor, an inductor, a diode, a switch, and a capacitor. The diagram is overlaid on a grid. The interface includes a toolbar at the top, a component list on the left, and a table at the bottom right.

General Data

Toolbars

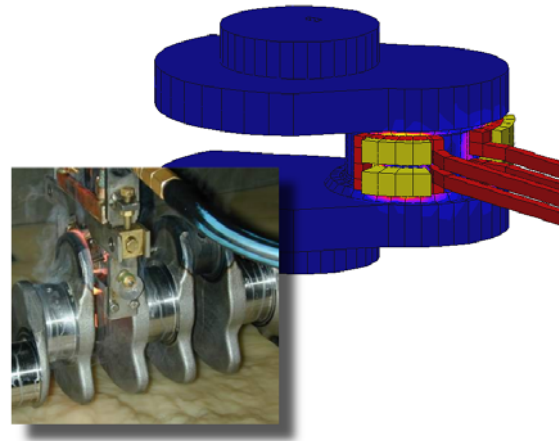
Graphical sheet

List of circuit informations

Type	Name	Parameters state	Connection state	Graphic representation	Potentials of terminals
+	CAPACITOR_1	Not defined	Connected	Valid	EQUIPOTENTIAL_4 EQUIPOTENTIAL_5 EQUIPOTENTIAL_2
+	COILCONDUCTOR_1	Not defined	Connected	Valid	EQUIPOTENTIAL_3 EQUIPOTENTIAL_3 EQUIPOTENTIAL_4 EQUIPOTENTIAL_4
+	DIODE_1	Not defined	Connected	Valid	EQUIPOTENTIAL_1 EQUIPOTENTIAL_2 EQUIPOTENTIAL_3
+	INDUCTOR_1	Not defined	Connected	Valid	EQUIPOTENTIAL_1 EQUIPOTENTIAL_2 EQUIPOTENTIAL_5
+	SWITCH_1	Not defined	Connected	Valid	EQUIPOTENTIAL_5 EQUIPOTENTIAL_5 EQUIPOTENTIAL_4
+	GROUND_1	Defined	Connected	Valid	EQUIPOTENTIAL_5 EQUIPOTENTIAL_5 EQUIPOTENTIAL_1
+	RESISTOR_1	Not defined	Connected	Valid	EQUIPOTENTIAL_1 EQUIPOTENTIAL_5 EQUIPOTENTIAL_5
+	VOLTAGESOURCE_1	Not defined	Connected	Valid	EQUIPOTENTIAL_1 EQUIPOTENTIAL_5 EQUIPOTENTIAL_2
+	THYRISTOR_1	Not defined	Connected	Valid	EQUIPOTENTIAL_5 EQUIPOTENTIAL_2

Benefits of using Flux for heat treatment

- Advanced CAD import capabilities:
 - » Capabilities to import both neutral and native CAD formats:
 - ✓ STEP, IGES, DXF, STL, SAT, Inventor, Pro_E, CATIA V4, CATIA V5



- » Advanced correcting functions to adapt the initial CAD draw to FEM calculation:
 - ✓ Automatic healing (for possible intersections,...)
 - ✓ Automatic faces stitching
 - ✓ Automatic solid assembly

Benefits of using Flux for heat treatment

- And also:

- » Full scripting and customizing capabilities thanks to Pyflux[®] command language
- » Easy multiparametric studies
- » A user-friendly graphical user interface
- » ...

