Steady state AC magnetic coupled with transient thermal: a new dynamic with Flux®.

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Heat generation is often a consequence of a current flow in a device, and designers often have to take into account this phenomenon. Thermal analysis has always been an important capability of Flux, and version 11.1 pushes a bit step forward the advanced thermal coupled simulation of electric devices.
In the coming article, you'll find a description of those Flux new capabilities, working on a simple example: cooking an egg in a pan with an inductive stove.

Principle of the basic example

For the general public, the origin of the heat source for an induction plate used to cook food is highly mysterious. The fact is that there is no flame and no electrical heating element. There is just a glass-ceramic cooking surface that stays cold when no cooking vessel is placed on it.
To illustrate the operating principle of such a device, we consider a pan of water we want to boil in order to cook… an egg (figure 1). Note that this is an axisymmetric model.

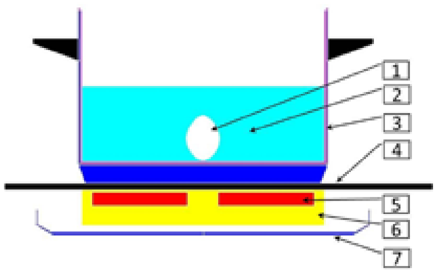


Fig. 1: A pan of water to heat with an induction stove.

Under the glass-ceramic plate, there is a field coil powered by AC current whose frequency is close to 25 kHz. Then, you need a cooking vessel made of a ferromagnetic material such as ferromagnetic stainless steel.
From there, the magnetic field created by current in the field winding generates an electric field and thus creates eddy currents inside the pan material. That produces Joule losses that heat the material. The diagram in Figure 2 illustrates the action and reaction at the heart of this phenomenon, using Maxwell's equations.
This shows that the advantage of the induction plate is that it imports electric power to be dissipated to the heart of container to be heated, saving energy in the process.
The performance of the device is primarily due to the magnetic properties (magnetic permeability), electrical properties (electrical conductivity) and thermal properties (thermal conductivity and heat capacity Cp) of the material used to make the pan.

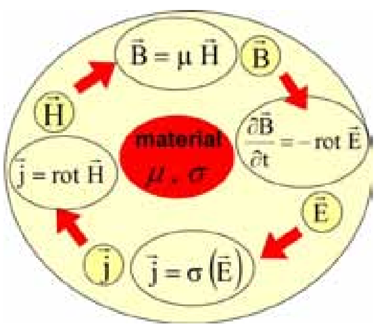
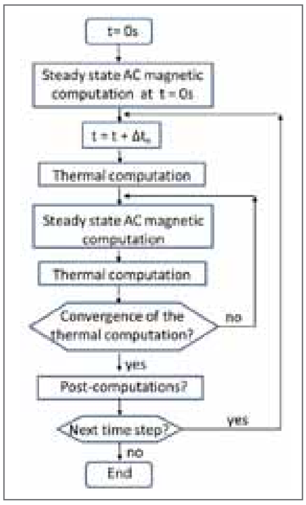


Fig. 2 - Losses in magnetic circuit, transient state, diffusion of magnetic induction.

Application simulated in Flux

Multiphysics approach

The complex nature of this operating principle requires a multi-physics approach when it comes to modeling. The application of steady state AC magnetic coupled with transient thermal used in Flux software allows users to perform this type of modeling. Two kinds of resolution are coupled to determine the resulting magnetic operating point: steady state AC magnetic resolution and transient thermal resolution. A graphical representation of the algorithm appears in Figure 3.
Very briefly, a steady state AC magnetic computation has to be performed to determine an electromagnetic working premise from which we can deduce dissipated Joule losses.
Then, a thermal calculation is made to determine the impact of these losses on the device's thermal balance. Afterwards, the electrical and magnetic characteristics of materials have to be updated. Several iterations can be performed to reach convergence of the thermal calculation. When this convergence is achieved, the next time step can be addressed.



The new version of Flux automatically handles the nesting of electromagnetic and thermal calculation loops. Furthermore, from a practical point of view, all magnetic, electrical and thermal parameters are available within the same environment.

Fig. 3: Steady state AC magnetic coupled with transient thermal computation - algorithm

By the end of the resolution, we can show, on the same figure, the distribution of isolines of magnetic flux superimposed with the resulting temperature map within all the components of our device at a given time of the transient thermal calculation (Fig. 4).

Drive and control of the power supply

This coupling between the electrical, magnetic and thermal aspects can also be useful for driving and controlling of power sources.

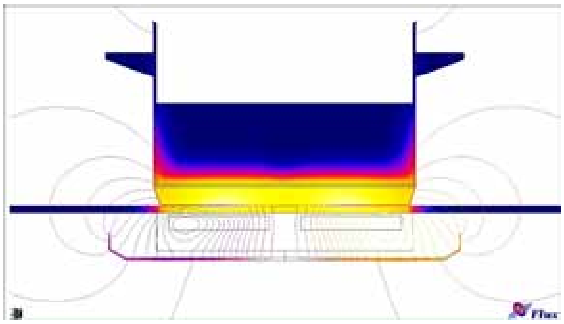


Fig. 4: Displaying of the magnetic flux isolines superimposed with the resulting temperature map.

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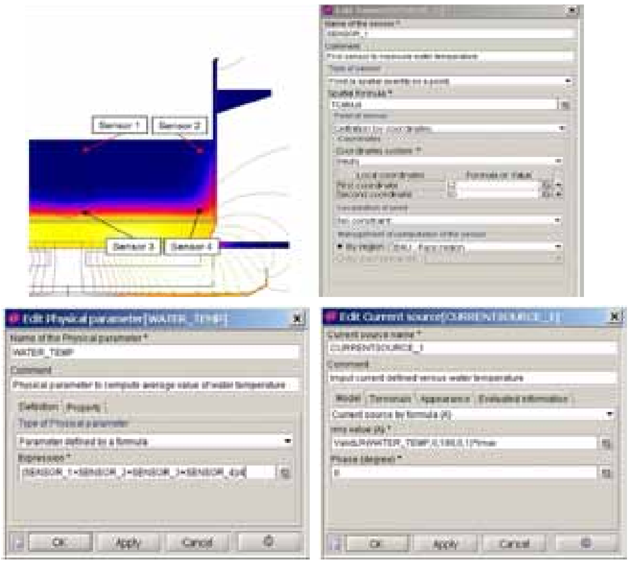

Fig. 5: Drive and control of the power source considering the average temperature of the water.

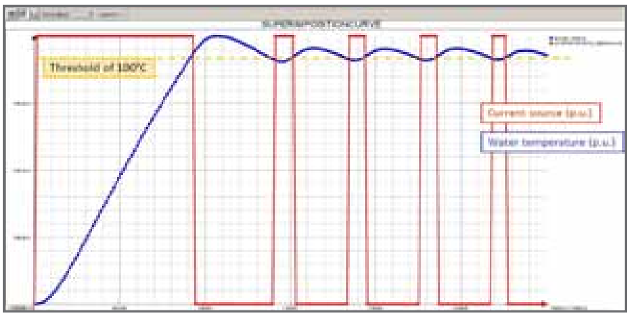

Fig. 6: Evolution of the average water temperature measured and controlled using four sensors.

This coupling between the electrical, magnetic and thermal aspects can also be useful for driving and controlling power sources. Returning to our pan of water, we defined the average temperature of water from a few measurement points (Fig. 5).
Then, from the information obtained from each calculation step, the supply of the field coil could be controlled to regulate the average temperature of the cooking water.
Finally, during post-processing of results, all these quantities can be extracted for analysis (Fig. 6). The graph shows that if the set threshold (100°C) is exceeded, the current delivered to the field coil is turned off and is reactivated when the temperature drops below the 100°C threshold.
These results also illustrate the impact of thermal time constants on the temperature changes, linked to the thermal characteristics of the device's components.
Whether for local computation, such as the computations on points, or the display of magnetic and thermal quantities, easy access to the usual physical quantities is available (Fig. 7).

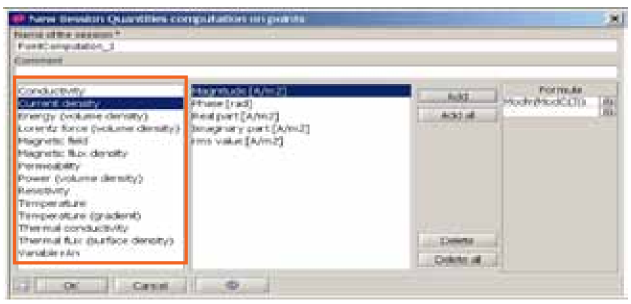

Fig.7: Computation on points – easy access to usual physical quantities (magnetic, electric or thermal).

It is the same when calculating for physical entities such as the amount of Joule losses dissipated in a component. It is possible to simultaneously compute and display the values of magnetic, electrical or thermal quantities.

» A few words about geometry and meshing...

With the latest version of Flux, the building of meshed geometry, a necessary basis for finite elements modeling, has become a quick and easy operation.
A "sketcher" is now available to allow the user to draw the device very quickly and very accurately like with a CAD (Computer Aided Design) tool used by mechanical engineers.
Then, the automatic meshing option allows model geometry to be meshed instantly. The geometrical dimensions are automatically taken into account in order to achieve an optimum mesh (Fig. 8).
And when, as is the case in our example, physical considerations such as skin depth must be taken into account, a macro function automatically adjusts the mesh on the borders of the regions concerned (Fig. 9).

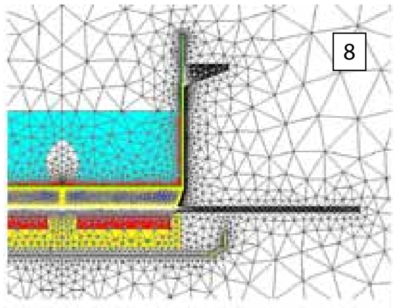

Fig. 8: Automatically taking specific geometry for meshing into account.

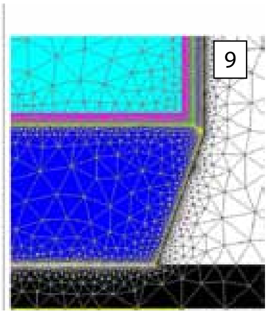

Fig. 9: A macro function available in Flux allows us to take into account the skin depth.

Conclusion

In conclusion, Flux now offers a more user-friendly approach to multi-physic problems such as thermal magnetic coupling.
From developing finite element models to analysing results with a powerful post-processor, everything has been done to allow the user to concentrate on key technical aspects of his studies.
All stages, useful from a modeling point of view but laborious and of little interest to the electrical engineer, have been adjusted to improve the efficiency of Flux:

- Building and meshing geometry,
- Description of the physical parameters of the model as well as the post-processing of results in a unique environment,
- Easy access to common quantities without having to describe complex mathematical formulae,
- The ability to group result calculations as lists of operation results, etc ...

All these improvement factors allow us to propose a tool whose interface can be easily adapted to the requirements of every function from a vast array of electrical engineering applications.
Concerning the example described above, it is easy to measure the energy efficiency of a cooking operation using an induction plate. We do, however, humbly admit that Flux is still unable to indicate quality levels in the resulting eggs. But watch this space, our development teams lack neither energy nor imagination!

Flux by CEDRAT