CEDRAT design solutions for electrical engineering NEWS

Using CEDRAT's Tool to Review Thermal Solutions

Patrick Lombard - CEDRAT.

Nowadays, it is more and more difficult to design electrotechnique devices without **considering thermal stress.** In more and more applications (electric vehicles, electric aircraft, etc.) there is a need to reduce weight and cost, increase efficiency, whilst maintaining security. **One possibility is to increase current for the same device, and therefore how to draw away the heat.** This is why conventional approximations need to be cross-checked with new tools. **These new tools have to be quick and precise in order to run parametric and even optimisation analyses.**
Of course, thermal analysis is already available in the Flux suite for induction heating, induction hardening, forging, etc. Dedicated applications have been created to couple magnetic AC steady state to thermal transient analysis, for instance. **What is new is easier and more effective coupling any type of magnetic application to thermal analysis.**
This article reviews what thermal analysis is, when the different tools were created, and looks at the latest advances in thermal analysis.

What is thermal analysis?

Thermal analysis **reveals the impact of power supply on the heat of the different components of a device.** A conventional project will include: one or more power supplies, conducting bodies, convection and radiation between a surface and a fluid. In the fluid you may have laminar flow or turbulent flow.

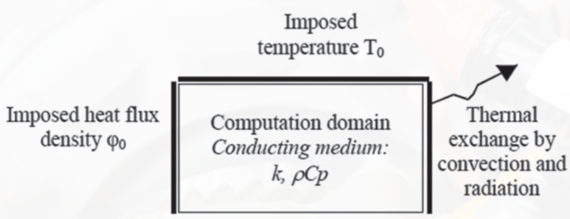


Figure 1: Typical thermal application.

One benefit of this type of computation is the temperature dependency of all material properties: magnetic materials lose their magnetic property at Curie temperature, resistivity increases with temperature.

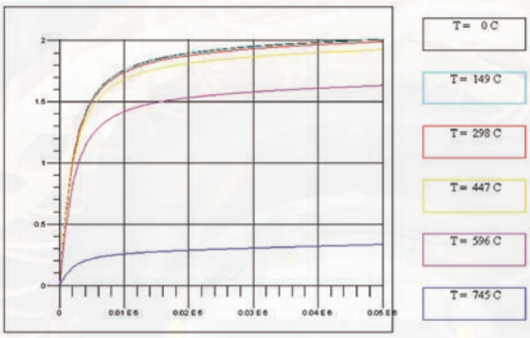


Figure 2: Magnetic property versus temperature.

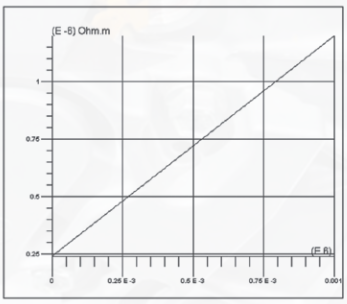


Figure 3: Electrical resistivity.

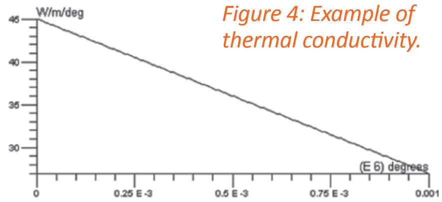


Figure 4: Example of thermal conductivity.

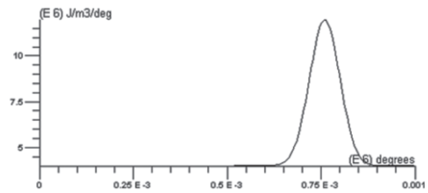


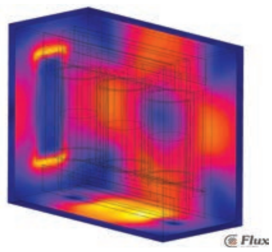
Figure 5: Thermal capacitance around Curie point.

Thermal conductivity and the thermal capacitance also vary versus temperature (especially around the Curie temperature).

Conventional thermal analysis tools

Traditionally, different methods are available for thermal analysis. The first is based on equivalent circuit parameters for thermal flow. This means identifying the circuit followed by the heat flow, and determining each component. This produces very quick solutions but needs calibration to be efficient. The corresponding tools are Motor-CAD, and also Portunus and Matlab®/Simulink solvers.

Figure 5b: Isovalues of current density on the tank surface.



When considering only conduction in solid bodies (and not in fluids, such as air), Finite Element tools such as Flux are appropriate. This produces accurate computation; convection and radiation coefficients must be known.
To take into account the whole thermal flow including fluids with turbulent or laminated flow, CFD code, such as CD-adapco/STAR-CCM+ or ANSYS/Fluent is a good tool. Hot spots can be determined, but it takes time to produce results.

CEDRAT's thermal tool history

Induction treatment has been considered as a key industry and CEDRAT delivered its **first magneto-thermal analysis tool under Flux 2D in 1986.** Initial features were improved with rotation in 1989, circuit coupling in 1992, and linear movement in 1994. **3D came in 2003**, with rotation and linear movement as well. Since 2003, any type of device with rotation or linear movement can be modelled under Flux in 2D and 3D. **In 2006, we added API compatibility to couple any Flux application to another Flux application or to an external tool such as MpCCi. In 2014**, we were able to **couple Flux to CFD code such as STAR -CCM+**. In 2015, we will add the possibility of **taking radiation between surfaces in 2D and 3D into account.**

In parallel, with the Portunus system simulator we have been able to handle equivalent thermal circuits since **2008**.

(see continued on page 13)

What are CEDRAT's tool advantages?

Since the beginning, Flux has offered numerous benefits:

- **Good material properties** (taking into account all temperature dependencies)
- **Specific dedicated regions** (line regions, thin regions, non meshed coils)
- **Meshing precision** (especially to model skin effect, penetrating slowly inside the body)
- **Parametric analysis** (any dimension can be parameterized including the mesh versus the frequency)
- **Circuit coupling** (ability to represent any type of circuit, using formula with voltage depending on point temperature)
- **Accuracy**

Latest improvements

New possibilities have arisen with new macros to **reveal current supply required to follow a specific thermal profile.** Flux can do one computation, carry out a test and then decide to keep going or redo the current step with a new power value. A **power supply limitation** can also be added. This feature was described in CEDRAT News n° 66.

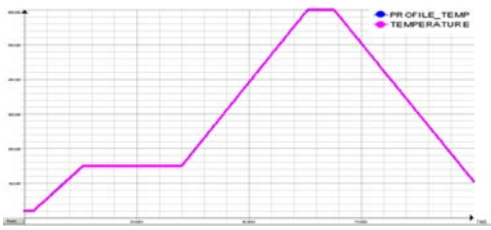


Figure 6: Targeted temperature & temperature obtained (curves are surimposed).

Another interesting feature is the ability to easily **represent a cooling system with a shower,** using formulae, including when the shower will appear. The graph shows the temperature fall with air or with a shower (for hardening purposes).

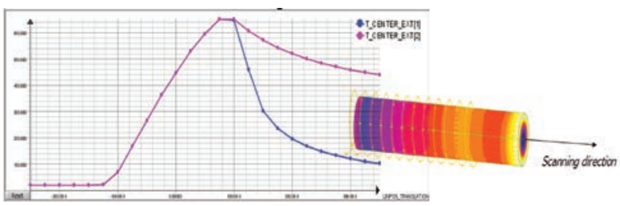


Figure 7: Temperature with air cooling or with shower cooling.

Multi-physics possibilities

In order to couple magnetic and thermal analyses, we have now 3 different solutions:

- **Couple Flux magnetic to Flux thermal application**,
- **Couple Flux magnetic to CFD code**,
- **Being part of a suite** (such as MpCCi). With Flux 12, it is now easier to couple different Flux applications to other Flux applications. This is also true for any type of magnetic analysis (static, AC or transient) for any thermal application (static or transient). Previously, it was possible, but meant writing specific command files in pyFlux language. To choose the most suitable application it is important to establish whether you are interested in static temperature (steady state) or temperature increase (how long it will take to reach the final temperature). This will define the type of thermal analysis you need.

> *Induction treatment has been considered as a key industry and CEDRAT delivered its first magneto-thermal analysis tool under Flux 2D in 1986.*

	Flux - Flux coupling	Flux - STAR-CCM+ coupling
Accuracy	Good global / average values in the different parts of the device	Best accuracy Determination of hotspots
Model set-up	Only Flus is used Flux user with thermal knowledge More flexibility in the applications	2 software to be run and coupled Geometry and mesh defined 2 times Thermal simulation expert required
Solving times	Reduced compared to CFD calculations	Several hours required
Price	Flux thermal additional module	STAR-CCM+ software

Table 1: Comparison between 2 methods for multi-physic applications.

We have applied this new coupling to the analysis of a PRIUS II motor for a specific working point. The project was defined for magnetic and thermal applications. After computing one electric period, the average power value is computed in the coil winding, magnet and sheet as iron losses. The average power losses are automatically transferred to thermal analysis. For each project, input and output values, coupling project type, etc. have to be defined, as described in the attached figure (cf figure 8).

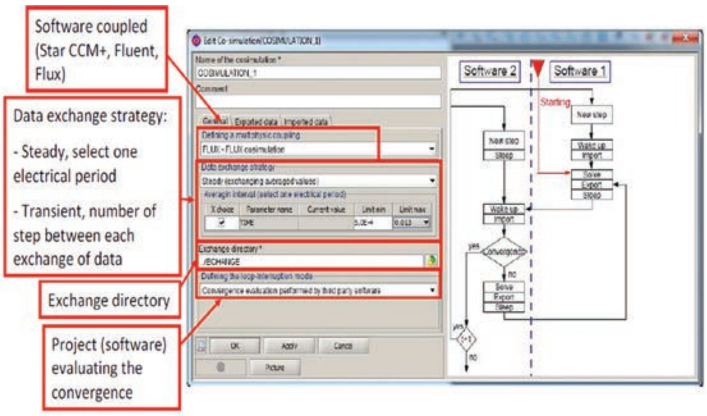


Figure 8: Defining the co-simulation project.

As regard losses and temperature, the result is as follows:

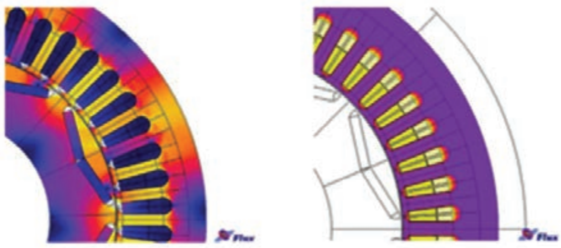


Figure 9a: Rising temperature.

(see continued on page 14)

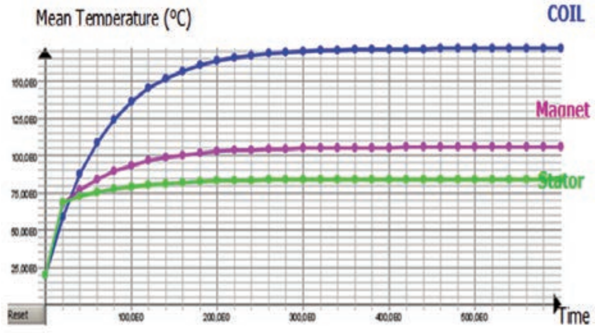


Figure 9b: Rising temperature.

A similar type of computation was done with a coupling using STAR-CCM+. Instead of representing one height in the magnetic part, one quarter has to be represented in the thermal part due to the cooling system (see figure 10). The result is presented in figure 11. We can see that water cooling close to the external stator part maintains the temperature close to 70°C, whereas the temperature is quite high in the end part of the coil winding.

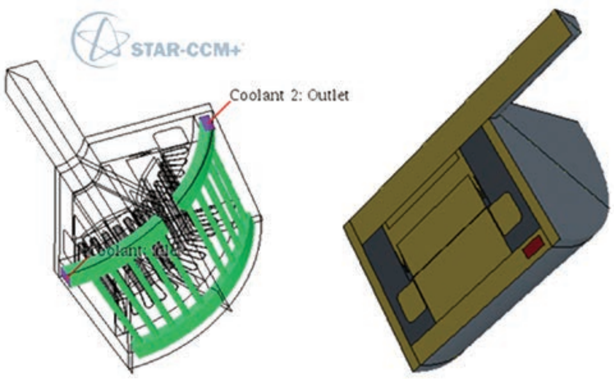


Figure 10: Prius II motor with cooling system with STAR-CCM+.

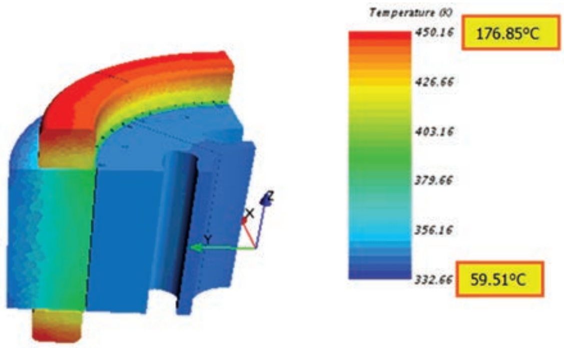


Figure 11: Final temperature in PRIUS II motor.

We can show an example of a multi-physic application using the Flux AC steady state magnetic application coupled with thermal computation with ANSYS/Fluent (CFD code) with an external tool. The goal is to analyse the heating of busbars. The example was developed by Schneider Electric using the **MpCCi tool**. This tool allows different software such as Abaqus, ANSYS, Flowmaster, Fluent, ICEPAK, FINE/Hexa, FINE/Open, FINE/Turbo, MATLAB, MD.Nastran, MSC.Adams, MSC.Marc, OpenFOAM, RadTherm, SIMPACK, STAR-CD, STAR-CCM+, etc. to be coupled.

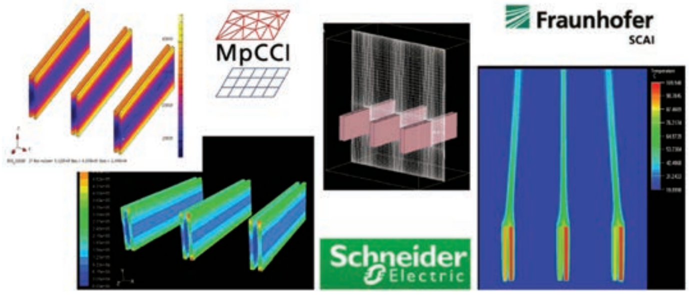


Figure 12: Heating of bus bars (courtesy of Schneider Electric).

Moving forward multi-physics application

Since 1986, many computations have been done involving thermal analysis coupled with magnetic analysis. CEDRAT has done its best to maintain its leading position in this field by **introducing new methods and new tools according to market demand**. CEDRAT's tools are well known for induction treatment, hardening and forging.

Our tools are also used by French cooks: I remember during an advanced training course one customer explaining that he was also using Flux to determine cooking time for liver, in order to cook "foie gras" in boiling water, without the internal temperature exceeding 57°C. The most difficult task was to find out the thermal characteristics of the liver.

We are now moving toward multi-physic applications for other electro-technical devices such as actuators, sensors and motors. This is why new couplings are now available, within Flux or with external partners such as STAR-CCM+ or MpCCi.

In order to help our customers with these new functionalities, we are working to **provide more documentation and more examples**. The documentation will explain how to determine conventional coefficients for convection, how to model airgap of motors, etc. Examples will include new 2D and 3D applications with induction motors and magnet motors.

We will also add the **radiation between surfaces in 2D and 3D**. This development and the documentation will come with Flux 12.1, planned for autumn 2015. This will produce **more accurate results**.

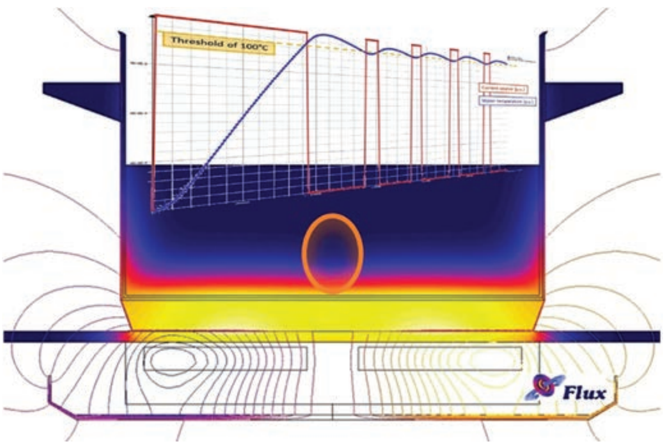


Fig. 13: Displaying of the magnetic flux isolines superimposed with the resulting temperature map.