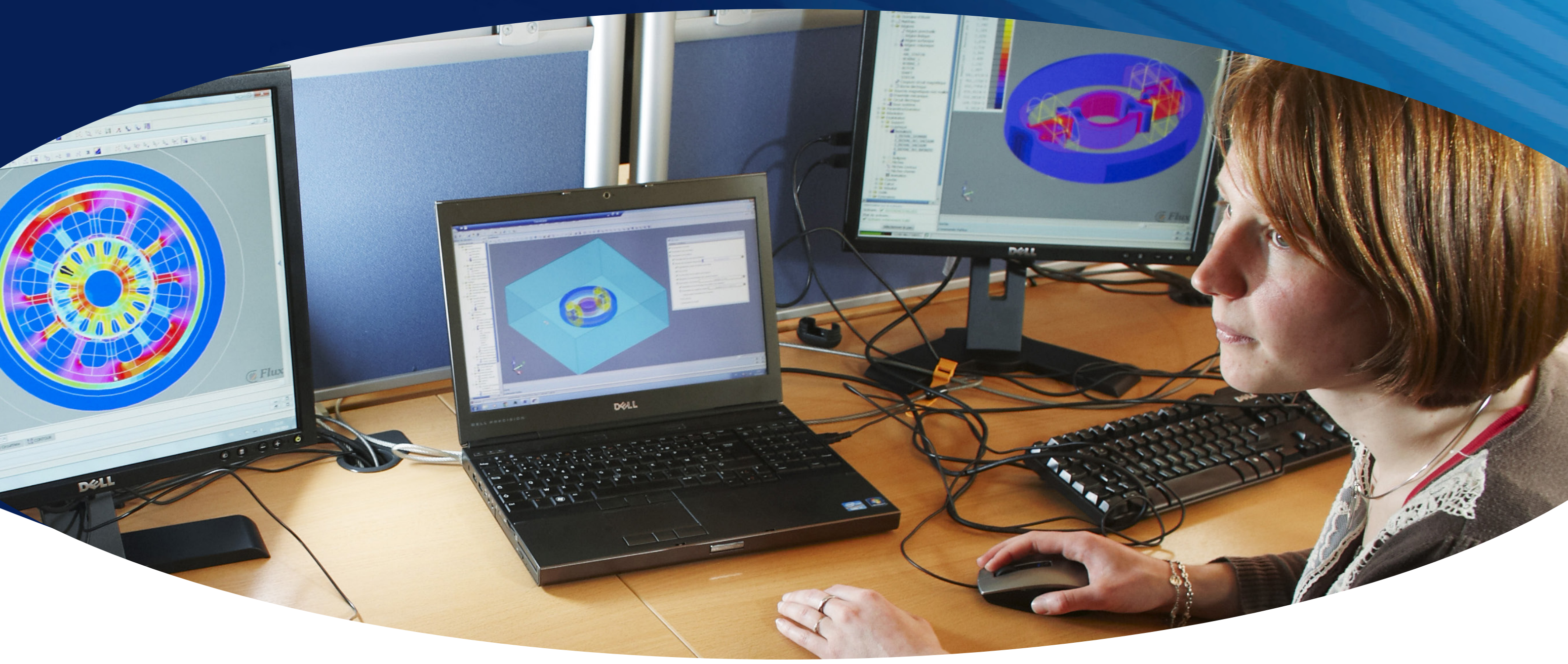
G2E lab
Grenoble Génie Electrique
Grenoble Electrical Engineering

Energy efficiency oriented

Highlights

2014



Models, Methods and Methodologies Applied to Electrical Engineering

Grenoble INP
Université Joseph Fourier GRENOBLE
cnrs
lanef Laboratoire d'Alliances Nanosciences-Energies du Futur
INSTITUT CARNOT Energies du futur

Foreword

MAGE: Models, Methods and Methodologies Applied to Electrical Engineering

The team develops mainly 2 themes of research consisting in

- *Extending the computing capabilities by focusing on methods of computational electromagnetism in continuous media, on models of materials for electrical engineering and on multi-physics and multi-methods coupling, and this with a multi-level approach from component to system.*
- *Helping the expertise and the design of devices addressing the themes of innovation, sizing and capitalization and management of knowledge.*

For this, the team works on many applications like micro systems, electrical machine, devices of power electronics, electromagnetic actuators, machine-converter-control, associations electrical networks. The team is linked with teams featuring other skills: computer science, mathematics, industrial engineering and social sciences.

These researches lead to the development of numerous generation of software tools like FLUX, MIPSE, INCA, CADES, LOCAPI, GOT, MacMems, Reluctool, DIMOCODE, ...

This activity results in academic production of high quality, but also in industrialization of software that are for some of them worldwide known and used. This is the case of FLUX2D and FLUX3D, industrialized by CEDRAT, thanks to a close collaboration over 30 years. This more recently the case with Vesta-System that is now industrializing CADES and Reluctool.

Contents

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Integral and finite element methods for the modelling of magneto-mechanical coupling

The magneto-mechanical coupling is modelled using different numerical methods for both physics. The magnetostatic problem is solved with an integral method without meshing the air domain. A method is developed to compute the magnetic force in the framework of the integral formulations. The mechanical problem is solved with a finite element method. This approach is well suited to model several systems (like MEMS) in which problems of accuracy could be present with a classic finite element method.

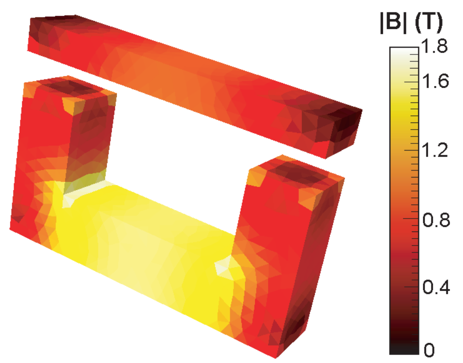

Figure 1 : Computed induction field for a contactor problem

1. Magnetostatic Modelling (Figure 1)

Development of a modelling tool based on the volume integral method.

Advantages:

- Free space no meshed
- Well suited for energy and force computations

Drawbacks:

- Full matrices

2. Magnetic force computation (Figure 2)

Several methods are available on the literature whereas they are not necessary relevant in the framework of the integral formulations. An adaptation of the virtual works to the integral methods has been developed.

3. Magneto-mechanical coupling (Figure 3)

The modelling of the magneto-mechanical coupling can be split in three steps:

- Resolution of the magnetostatic problem using a volume integral method.
- Computation of the magnetic force.
- Resolution of the mechanical problem using a element finite method.

The air is not meshed and the same mesh could be used for the both problems.

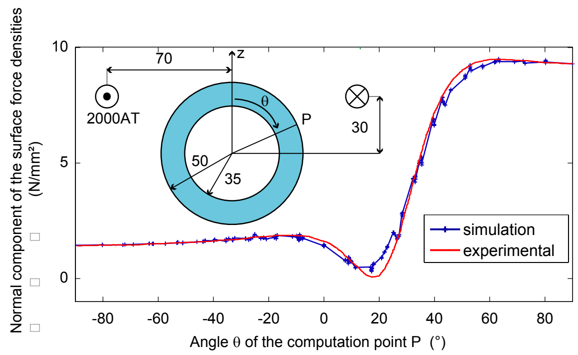

Figure 2 : Computed magnetic force for a hollow sphere problem

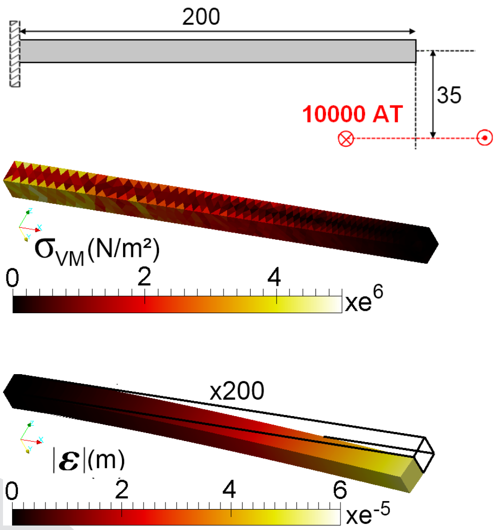

Figure 3 : Computed stress and strain for a cantilever beam problem.

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GOT: A platform for modeling, model reduction, analysis and optimization

GOT is a powerful and reliable optimization tool which can solve any optimization problem with one or several objectives, with or without constraints. A full range of optimization algorithms (deterministic and stochastic) specifically adapted to interact with simulation softwares, enables the user to select the best method for his application. A user friendly interface with interactive commands, helps the user to easily define and optimize his problem. Repetitive tasks can be tackled programmatically with script files. GOT is also a platform usable for building dedicated applications. Thanks to its advanced functionalities for indirect optimization, model reduction and uncertainties, GOT-It can efficiently boost the design and optimization process of any industrial device.

We capitalize our experience in the software GOT, which is particularly well suited to optimization by numerical simulations. Here are the main features:

Modeling

- Parameters (continuous or discrete, certain or uncertain)
- Functions (analytical expression, symbolic derivation, probabilistic deviation, worst case deviation)
- ICAr, Matlab and Excel connections
- Checking of measure units consistency
- Plugged business operators

Model reduction

- Screening (selection of the most influent parameters)
- Response surface (Polynomial and Radial basis function)

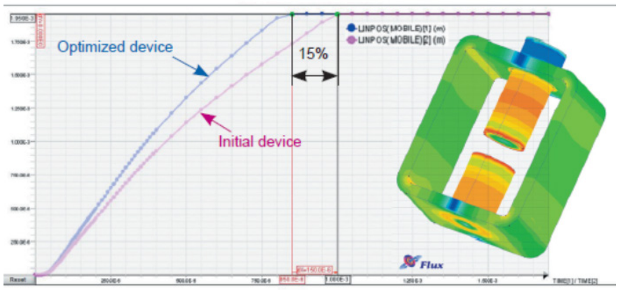
Analysis

- Evaluators (deterministic and stochastic, interval analysis)
- Plotters (Y(X), Z(X,Y), Isoval(X,Y), ...)

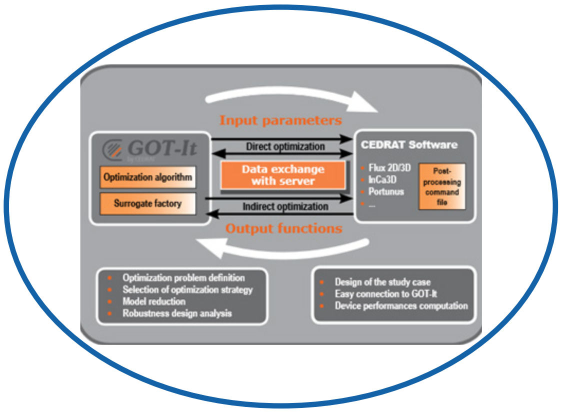
Optimization

- Optimization problems (objectives, constraints, uncertainties on control or design parameters)
- Optimization algorithms (SQP, GA, Niching, GMGA, ...)
- Decision-making (sensitivity/robustness of solutions, Pareto frontier, ...)

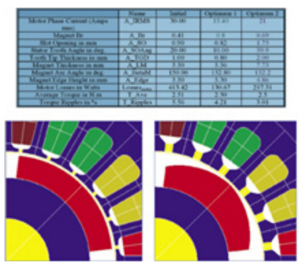
Virtual prototyping with FEM, BEM, ... induces specific difficulties due to remeshing noise, missing gradient, large computation time that can be solved by screening, response surface methodology and dedicated optimizers (Sequential Surrogate, Hierarchical Latin Hypercube).



Optimization of an actuator



Features of GOT-It (industrial version of GOT) by CEDRAT company


Optimization of a permanent magnet machine

Applications of the platform

- Cours et Travaux pratiques en ligne: ENSE3 A2 Optimisation et plans d'expérience, 2001-2014, http://chamilo2.grenet.fr/inp/courses/ENSE3M2SEMAAAA0/
- FGot: Featuring a Genuine Optimization Tool, a free software by G2Elab, 2001-2014, http://forge-mage.g2elab.grenoble-inp.fr/project/got
- LocapyNavy: Locapi sofware for navy applications, a dedicated software by G2Elab (2009-2013);
- GOT-It: Optimization software for devices and system in electrical engineering, an industrial software by CEDRAT and G2Elab, V1: 2011, V2: 2013, http://www.cedrat.com/en/software/got-it.html
- MaGot: MAgnetic Genuine Optimization Tool, a dedicated software by Schneider Electric and G2Elab (2014)
- CorOnS: CORosion ON Surfaces, a dedicated software by DGA and G2Elab, 2013
- MipseGUI: A Graphic User Interface for MIPSE, by G2Elab, 2013-2014

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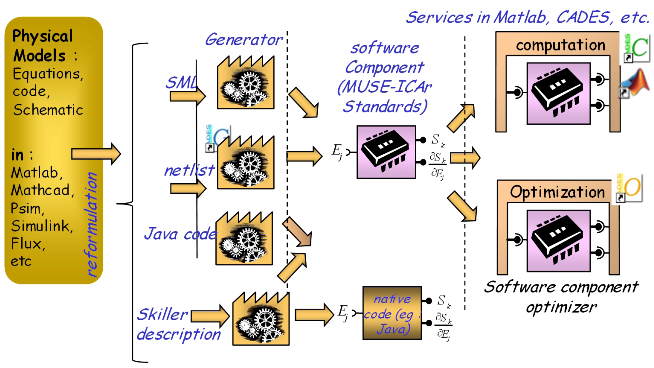
CADES : Component Architecture for Design of Engineering Systems

Use of the Software Component Paradigm for the Optimization of Engineering Systems

Software component is a recent paradigm emerging in computer science and software engineering. It offers the opportunity to define new architectures of optimization software in which the end user can easily, and without any programming skills, connect models to optimisation algorithms, both of them encapsulated in software components. In this way, Cades framework offers a component architecture for the modelling and design by optimisation algorithm. A software component standard is proposes to support the modelling: ICAr and Muse. Cades also proposed modelers, i.e. software tools for the modelling in specific domains.

1. ICAr/Muse Software Components

Software components allows to share model which intern content can be analytical, numerical or both. In this way, the team Mage has proposed a standard to support the modeling for the sizing of electrical components or systems, using optimization algorithms. This standard has been extended in collaboration with Vesta System, specifically in the context of ANR projects on building energy management. This gives a new standard, including dynamic simulation abilities: MUSE (www.muse-component.org).



Cades architecture

2. CADES

CADES is component architecture for design of engineering systems. It proposes several formalisms to describe models. Among them :

- A language for the modelling of analytical model
- Modelling based on the magnetic moment method and semi-analytical electromagnetic integral formulations
- Modelling based on equivalent electrical circuits (magnetic, electrical, thermal, etc.)
- The ability to integrate complex simulation application thanks to the software component paradigm: Flux, Portunus, PSpice, etc.

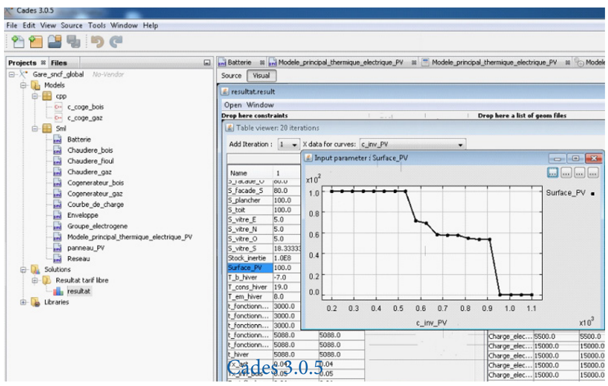
From these formalisms, CADES framework has several software tools that transforms these representations into executable programming code or software components, or that translate the models into modelling languages (e.g. : Modelica or VHDL-AMS). Among them : Reluctool, MacMMems, PowerSysTool.

A specificity of these generators, is their ability to create automatically the computation code of the models, and their exact jacobien (often necessary for optimisation algorithms dealing with numerous constraints) Cades framework has also modelers to use the generated software component:

- computation possibilities
- sensibility analysis
- optimisation (SQP, genetic algorithms, Pareto frontiers, etc.)
- post-processing analysis (after optimisation)

3. Industrialisation

Vesta-System Company has been created in 2011 for the valorisation of Cades framework and building energy management. Since 2011, Cades is co-developed by G2Elab and Vesta-System.



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Collaboration : G2Elab - Vesta-system
http://www.cades-solutions.com

MIPSE: Generalized software Platform for the development of electromagnetic formulations

The MIPSE research project aims to lay the software and methodological foundations for the implementation of a multi-level and multi-method numerical simulation platform, enabling a fast and robust study of low and average frequency electromagnetic formulations. This platform, based on several numerical methods which can be coupled (Finite Element method, Integral method, circuit solver), has to insure a good efficiency in terms of computing time, moreover, it has to propose an efficient and robust development environment.

1. Technical Choices

Programing on a same language: JAVA.

- Multiplatform, Object-oriented.
- Automatic management of the memory.
- Own computing libraries: less performant than other languages(C).

What is lost in computing time is gained in maintenance and debugging time.

2. Integral Methods

Principal method in the platform

- Based on distant interactions.
- Free space non meshed.

2 main drawbacks:

- The assembling interaction matrix is full: $O(N^2)$ computing and storage complexity.
  > Compression: ACA, HCA, FMM.
- There are singularities due to the integration kernel, especially on self and near-element interactions.
  > Integration strategies:
  - Fixed or adaptive gauss points integration
  - Set the elements to correct (self, neighbor, enclosing sphere...)
  - Type of correction (analytical, value cancel , more gauss points...)

3. Scientific impact

- Development of original and performant formulations
- Numerical Method Hybridation.
- Model order reductions.
- Simulations on more complex geometries

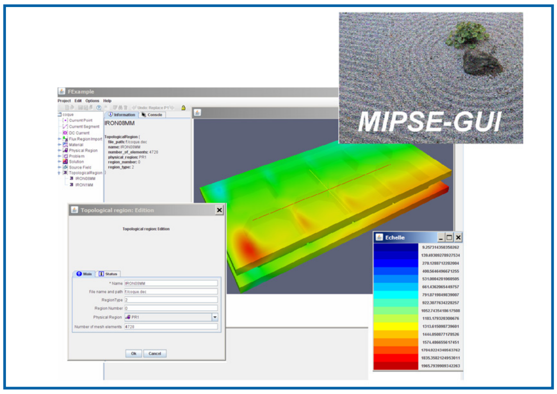

Fig1. Computing Time performances for the FMM. The complexity tends to O(NlnN) instead of $O(N^2)$ without compression

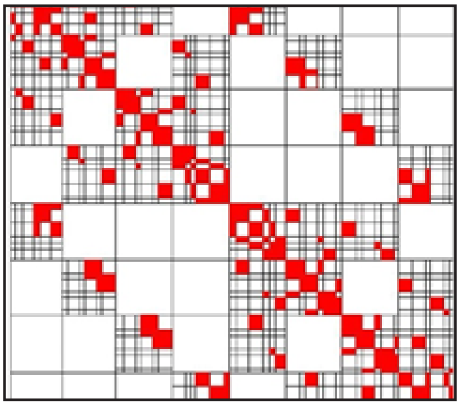

Fig2. Hierarchical matrix decomposition used to perform HCA and ACA

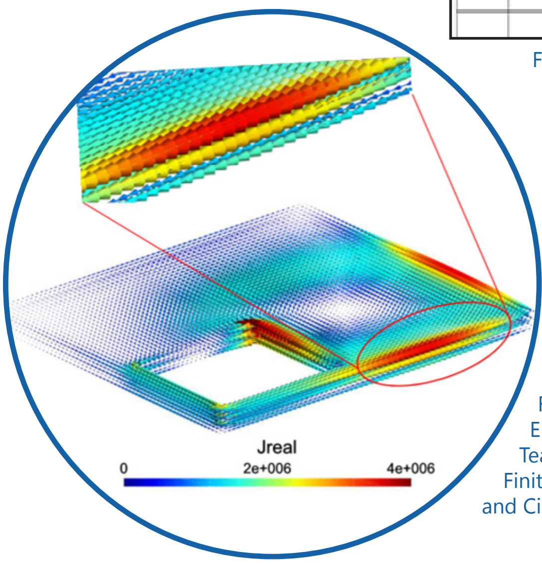

Fig3. Electromagnetic modeling of Team Workshop problem 7: Finite Element, Integral Methods and Circuit Solver coupling

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Electrical energy systems modeling framework including interoperability of expert tools based on modelling language standards (VHLD-AMS/Modelica) and software component standard (ICAr/muse)

Today's challenge is to make an efficient design of ***an electrical energy system****, including* ***different simulation domains*** *(physical or not), and* ***different experts with their own tools****. A system global modeling, taking into account its various components, must be performed by using* ***interoperability*** *approaches. A* ***white box*** *approach based on* ***Modelica*** *or* ***VHDL-AMS languages*** *is adopted, as well as a complementary* ***black box*** *approach based on a* ***software component*** *standards in order to overcome the first approach limitations. Main concepts are: (1)* ***automatic model translation*** *from modeling languages to others; (2)* ***plug-in and plug-out*** *concepts that ensure generation and use of software components from modeling tools to others.*

1. System design approaches

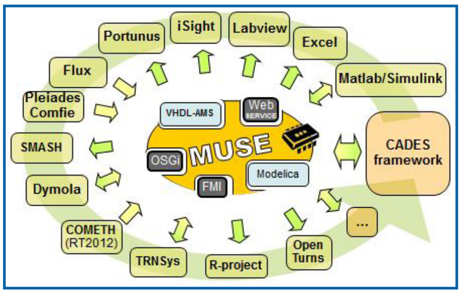
Different formalisms have to be considered:

- **Modelling language** standards (VHDL-AMS or MODELICA) preferred for system level simulation. It provides an explicit model (white box), strongly coupled with others models (mechanical, economic...). But, it is not easy to introduce accurate models such 2D/3D partial differential equations, or other modeling formalisms such as multi-agent modeling.
- **Software component** standards (black box ICAr/MUSE), a complementary approach for complex models, provided as a binary compiled code. It offers models portability and generic reuse concepts, but since it expose only its services, system is most of time built using weak couplings of components.

Both approaches have interesting properties in order to achieve system modelling, including tools to manage interoperability issues of expert modelling tools, based on VHDL-AMS/MODELICA and ICAr/MUSE standards.

2. System Modelling Framework

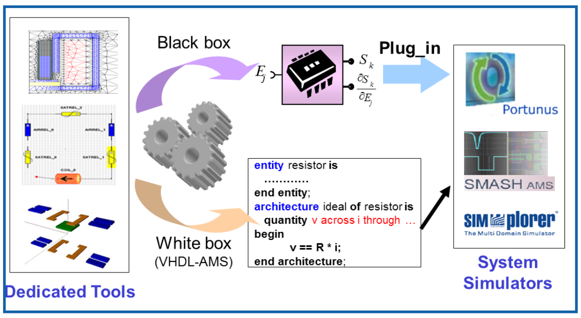
As illustrated in fig 1, interoperability between modelling and simulation tools is ensured by our MUSE standard (www.muse-component.org) and/or other standards.
CADES Framework (http://www.cades-solutions.com) implements this framework.



Interoperability framework

3. Application to mechatronic systems

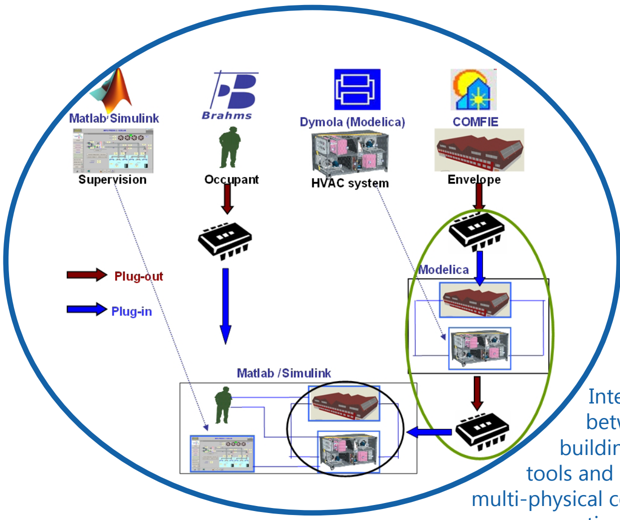
Reference : Abir REZGUI Thesis



Interoperability between expert electromagnetical modeling tools and software for multi-physical coupling and time simulation

4. Application to building systems

Reference : Sana GAALOUL Thesis



Interoperability between expert building modeling tools and software for multi-physical coupling and time simulation

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ANR Siminthec, ANR Mocosymec, ANR Plumes.

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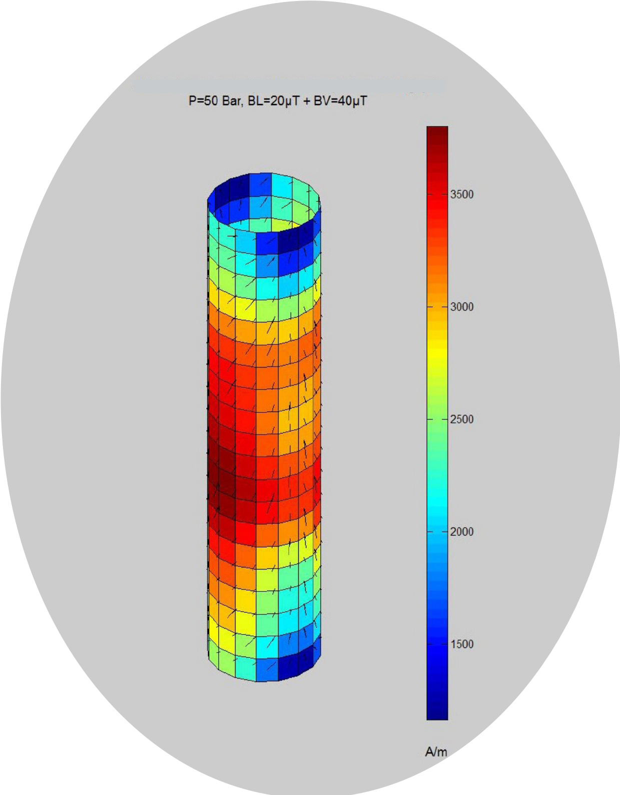
French Naval Academy Award granted to Antoine Viana Ph. D. Thesis



Each year, the French Naval Academy, funded in 1752, grants an Award to the author of a Ph.D. Thesis, presented the year before. The naval topic of the thesis may belong to any field, like history, science, economy, law, human sciences...Antoine Viana presented is thesis on october 1rst 2010. His study has been magnetoelasticicity applied to vessels. His research was carried out in the team in Low Fields of G2Elab (Grenoble Electrical Engineering Laboratory), in collaboration with French D.G.A. (Ministry of Defense). Magnetoelasticty is responsible for magnetic variations due to high mechanical stress. Antoine Viana solved the Jiles-Atherton equation in the particular case of a steel hollow cylinder, under increasing internal pressure, allowing the prediction of the magnetic induction variation with stress. Also, inverse problem resolution helped to determine magnetic distribution inside the steel, from external magnetic measurements. Thesis Title: "Study of magnetoelasticity in low field and under high mechanical stress"

Thesis Summary :

Application of mechanical stresses on a ferromagnetic material leads to modification of its magnetic characteristics. This is known as the magnetoelastic effect. Our study focuses on the modeling of this effect on a ferromagnetic hollow cylinder, when the latter is undergoing an internal increasing pressure, in a low magnetic field. The Jiles-Atherton model for the evolution of magnetization with stress is particularly well suited to our problem. This model is given as a differential equation for which no general analytical solution exists. In the case of a thin ferromagnetic shell, the Jiles-Atherton equation can also describe the variation of external magnetic induction with mechanical stress. In the case of our cylinder, it is then possible to exhibit an analytical solution to that equation, expressed in terms of magnetic induction. This solution makes it possible to predict the variation of external induction with pressure. Then, usage of an inverse problem solver leads to the determination of the evolution of magnetization with pressure inside the shell of the cylinder, based on measurements of external induction performed on magnetic sensors located in the vicinity of the shell. An vectorial analytical law is then proposed for the magnetization, and validated using measurements performed on our prototype.

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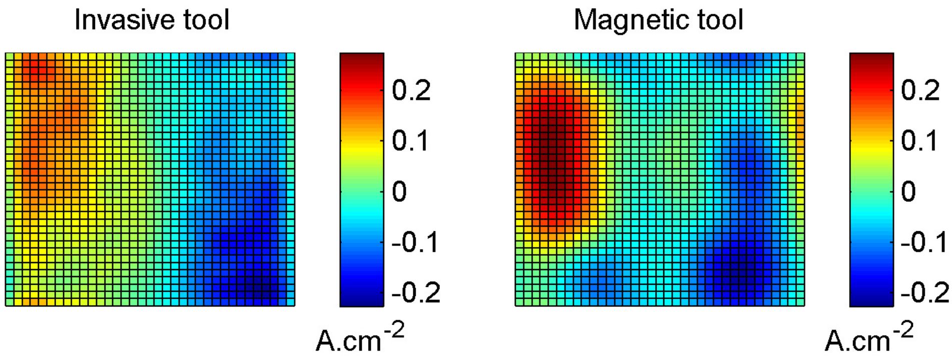
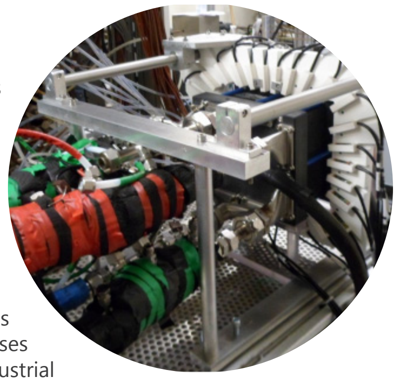
Current Distribution Identification in Fuel Cell Stacks from External Magnetic Field Measurements



Oxygen starvation of the stack: comparisons between currents density obtained with internal measurements (left) and with magnetic inverse problem (right).

Fuel cells are energy conversion devices that produce electricity directly from hydrogen and oxygen. A stack is an assembly of elementary cells that allows the creation of devices with high power. Currently, in spite of recent undeniable progresses, fuel cell stacks present certain drawbacks and improvements must be made in order to use them in real industrial application. They are prone to chemical, mechanical, or thermal hard constraints that inevitably lead to their degradation. These phenomenons are still not very well understood but non-uniform fuel/air flows, hot spots and non uniformity of materials within the stack can be the reasons of such degradations. In order to better understand the real behavior of stacks, the knowledge of local current density flowing within the system is fundamental. If the global value of the current is obvious to measure (with a simple ammeter), getting its local densities is not so easy. If some intrusive technics exist, their drawback is that the internal presence of sensors in the stack disturbs its operation mode. Then it is hard to discriminate if the faulty mode is due to the stack itself or to the diagnosis set-up.

This work aimed to develop an innovative non-intrusive diagnostic method for fuel cell stacks that provides a significant improvement in terms of estimation quality in comparison with existing non-invasive tools. The technique proposed here is to measure the magnetic field around a fuel cell in operation. Knowing the relationship between currents and this field, it becomes possible to evaluate the internal current density by solving an inverse problem.
The originality of the approach presented here is that it requires a very small number of magnetic field measurements (thirty against several hundred for what has been done so far). The instrumentation is facilitated and the use of a robot moving a sensor is not necessary.
Thirty sensors are fixed around the stack and enable an instantaneous measurement (against at least fifteen minutes with a robot). The major advantage is that the internal state of the stack does not vary during the measurement time. It lies on the use of original current bases and of a sensors array configuration developed in order to be only sensitive to current inhomogeneity. The approach is robust, enabling the use of accurate magnetic fluxgate sensor with a low range of measurements (less than 200 µT). The method has been validated on several test cases and has shown its potential on industrial real stacks.



Magnetic sensors network surrounding a fuel cell stack of PSA instrumented at CEA-LITEN

This project has been supported by a “BQR” (Bonus Qualité Recherche) of Grenoble INP and by ANR (French Reseach National Agency – “Omniscient” project). It has been conducted in collaboration with LEPMI (Laboratoire d’électronique et de physico-chimie des matériaux et des interfaces), LMGP (laboratoire des matériaux et du génie physique), CEA-LITEN, Helion (AREVA) and PCA Peugeot Citroën.

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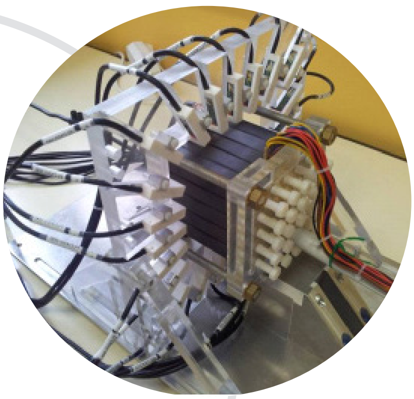
Further reading

Diagnostic non invasif de piles à combustible par mesure du champ magnétique proche
Mathieu Le Ny
thèse de l’Université de Grenoble, Ecole doctorale EEATS, Spécialité Génie Electrique, 2012.

Current Distribution Identification in Fuel Cell Stacks from External Magnetic Field Measurements
M. Le Ny, O. Chadebec, G. Cauffet, J-M. Dedulle, Y. Bultel, S. Rosini, F. Fourneron, P. Kuo-Peng
IEEE Transaction on Magnetics, 49, 5, (2013), 1925-1928



Magnetic sensor network calibration of a stack simulator

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