20.4 - 24.4. 2015, 5 ECTS PhD course on
Constitutive laws for electro-magneto-mechanical behaviour in electrical machines and devices

Location: Aalto University, Otaniemi Campus, ELEC (E111, H302, H402)
Lecturers: Professor Laurent Daniel, Laboratoire de Génie Electrique de Paris, France
Professor Reijo Kouhia, Tampere University of Technology, Finland
Dr. Paavo Rasilo, Aalto University, Finland

Person in charge: Prof. Anouar Belahcen, Aalto University, Dept. of Elec. Eng. and Aut.
Language: English
Enrolments: https://eage.aalto.fi/?fs/en/PhD_course
Schedule: The course will start on **Mon. 20.4 at 12.00** and ends on **Fri. 24.4 at 17.00**. During the week the course is every day from **9.00 to 17.00**. Detailed schedule is at the end of this leaflet.

Electrical steel used in **electrical machines** and **transformers** is only one of the Ferroic materials used in electrical engineering. The term Ferroic refers to ferromagnetic, ferroelectric or ferroelastic materials, which exhibit a macroscopic behaviour strongly related to the evolution of their microstructure under an external loading. Several types of external loadings such as **temperature**, **stress**, and **electromagnetic field** can induce a change in the so-called domain microstructure, and this change can in turn provoke several types of response such as **strain**, **magnetisation**, or **polarisation**. The behaviour of Ferroic materials is hence **multiphysic** by nature. This property makes Ferroic materials particularly interesting for the development of **compact energy conversion devices** such as actuators and sensors. It can also be a nuisance like **vibrations** and noise induced by magnetic field in electric transformers. In order to design devices based on the use of Ferroic materials under coupled loadings, specific **modelling tools** must be introduced.

This course is dedicated to the modelling of Ferroic materials under **coupled loadings**. It will be mainly applied to ferroelectric materials for the development of **piezoelectric** actuators, and to ferromagnetic materials for **electrical machines**. Due to the strong connexion between microstructure and macroscopic properties, specific **multiscale approaches** are introduced to describe the material behaviour. Further, the continuum thermodynamic based approach for the magnetomechanical coupling will be introduced and the effect of these coupling on the modelling of eddy currents will be explained altogether with loss computation and measurement methodologies.

Pre requisites: Basics in Electrical Engineering and electromagnetism

Assessment: Presence (30%), Simulations and exercises (40%), Learning Diaries (30%)

Objectives: One objective of the course is to highlight the coupled nature of Ferroic material behaviour and the role of the material heterogeneity. The other objective is to introduce **magnetomechanical modelling** approach and enable **loss computation** methodology. At the end of the course the students will be able to derive coupled constitutive laws for ferromagnetic or ferroelectric materials based on a micro-macro approach and use these equations in the **modelling of electrical machines** for the loss computation.

Content of the course

1. Introduction to constitutive laws and coupled behaviour
2. Ferroelectric and ferromagnetic materials: the role of microstructure.
3. Local characterisation of ferroelectric behaviour: a high energy x-ray analysis
4. Heterogeneous materials: the need for micro-macro approaches
5. A multiscale approach to the behaviour of Ferroic materials
6. Macroscopic approach to magneto-elastic couplings
7. Eddy currents and loss computation in electrical machines

The lecturers

Prof Laurent Daniel received his Engineering degree (Grande Ecole) from ENSAM, Lille and Paris, France in 1999, He did his Master's in Mechanics and Materials Science at the University of Paris 13, France, in 2000 and his PhD in Mechanics and Materials Science at Ecole Normale Supérieure de Cachan, France, in 2003. In 2011 he carried out his Habilitation in Physics (HDR) at the University of Paris-Sud, France. Since then he is Associate Professor at University of Paris-Sud and is the Director of the Automotive Mechatronics Chair.

Prof Laurent Daniel is the author or co-author of 49 peer-reviewed publications in international journals, 53 international conference communications, and 37 national conference communications. His main research interests are multiphysics and mechatronics systems, constitutive laws for coupled phenomena, micromechanics, multiscale methods, homogenization, smart materials, ferromagnetic materials, magnetostriction, ferroelectric materials, magnetoelectric effect, multiferroics, high energy x-ray, and neutron diffraction.

Prof Reijo Kouhia received the Dr (Tech) degree in mechanical engineering from Helsinki University of Technology, Finland, in 1999. Since then he worked as Senior Researcher in the same University. Since 2013 he is Professor of solid mechanics at the Department of Mechanical Engineering and Industrial Systems at Tampere University of Technology. His research interests are mathematical models and formulations for FEA, especially non-linear problems in continuum mechanics and their numerical solution.

Dr. Paavo Rasilo received the M.Sc. (Tech.) and D.Sc. (Tech.) degrees in electrical engineering from Aalto University, Espoo, Finland, in 2008 and 2012, respectively. He is currently a Postdoctoral Researcher in the Department of Electrical Engineering and Automation, Aalto University School of Electrical Engineering, Espoo. His research interests include numerical modeling of electrical machines, as well as power losses and magnetomechanical effects in soft magnetic materials.

Prof. Anouar Belahcen received the B.Sc. degree in physics from Sidi Mohamed Ben Abdellah University, Fes, Morocco, in 1988 and the M.Sc.(Tech.) and Doctor (Tech.) degrees from Helsinki University of Technology (currently Aalto University), Espoo, Finland, in 1998 and 2004, respectively. From 2008 to 2013, he was an Adjunct Professor in the field of coupled problems and material modeling with Aalto University, where, since 2013, he has been a Professor of energy and power. His research interests are numerical modeling of electrical machines, particularly magnetic material modeling, coupled magnetic and mechanical problems, magnetic forces, and magnetostriction.

Tentative schedule of the course

	Monday 20.4	Tuesday 21.4	Wednesday 22.4	Thursday 23.4	Friday 24.4
9:15 - 10:00		Role of microstructure	X-ray analysis	Role of microstructure	Multi scale approach
10:15 - 11:00		Role of microstructure	X-ray analysis	Role of microstructure	Multi scale approach
11:15:12:00		Calculation exercse	simulation exercices	simulation exercises	simulation exercises
12:00 - 13:15	Introduction	Lunch	Lunch	Lunch	Lunch
13:15 - 14:00	Introduction	Role of microstructure	X-ray analysis	Multi scale approach	Multi scale approach
14:15 - 15:00	Calculation exercise	Macroscopic approach	Eddy currents	Loss measurements	Loss computation
15:15 - 16:00	Calculation exercise	Macroscopic approach	Eddy currents	Loss measurements	Loss computation
16:15 - 17:00		simulation exercises	simulation exercices	simulation exercises	simulation exercises