

Date: Sunday, 28/Jun/2015**10:00am - 6:00pm Registration**

Delta Hotel Lobby

6:30pm - 8:00pm Welcome Mixer

Redpath Hall

Date: Monday, 29/Jun/2015**7:30am - 5:00pm Registration**

Foyer

8:30am - 9:10am Opening: Opening ceremony

Session Chair: David Lowther

Leacock Bldg #132

9:10am - 10:10am OA1: Overview

Session Chair: David Lowther

Session Chair: Arnulf Kost

Leacock Bldg #132

10:10am - 10:30am Coffee break

Lounge

10:30am - 12:15pm PA1: Mathematical modeling and formulations 1

Session Chair: Szabolcs Gyimóthy

Session Chair: François Henrotte

Cafeteria

10:30am - 12:15pm PA2: Wave propagation 1

Session Chair: Zhuoxiang Ren

Session Chair: Jon Webb

Lounge

10:30am - 12:15pm PA3: Novel computational methods for machines and devices 1

Session Chair: Claude Marchand

Session Chair: Erich Schmidt

Lounge

12:15pm - 1:45pm Lunch

La Plaza

1:45pm - 3:25pm PA4: Optimization and design 1

Session Chair: Abdul-Rahman A. Arkadan

Session Chair: Christian Magele

Cafeteria

1:45pm - 3:25pm PA5: Mathematical modeling and formulations 2

Session Chair: Gérard MEUNIER

Session Chair: Patrick Kuo-Peng

Lounge

1:45pm - 3:25pm PA6: Multi-scale modeling and homogenization; Electromagnetic sensors and metrology

Session Chair: Andrzej Demenko

Session Chair: Stephan Russenschuck

Lounge

3:25pm - 3:50pm Coffee break

Lounge

3:50pm - 5:30pm OA2: Mathematical modeling and formulations

Session Chair: Markus Clemens

Session Chair: Raffaele Martone

Room #0100

Date: Tuesday, 30/Jun/2015**7:30am - 5:00pm Registration**

Foyer

8:30am - 10:10am OA3: Optimization and design

Session Chair: Oszkar Biro

Session Chair: Kay Hameyer

Room #0100

10:10am - 10:30am Coffee break

Lounge

10:30am - 12:15pm PB1: Static and quasi-static fields

Session Chair: Zsolt Badics

Session Chair: Osama Mohammed

Cafeteria

10:30am - 12:15pm PB2: Material modeling 1

Session Chair: Johan Gyselinck

Session Chair: Tetsuji Matsuo

Lounge

10:30am - 12:15pm PB3: Software methodology; Education

Session Chair: Jean Bigeon

Session Chair: Sheppard Salon

Lounge

12:15pm - 1:45pm Lunch

La Plaza

1:45pm - 3:25pm PB4: Optimization and design 2

Session Chair: Hyun-Kyo Jung

Session Chair: Joao Pedro Assumpcao Bastos

Cafeteria

1:45pm - 3:25pm

Lounge PB5: Numerical techniques 1

Session Chair: **André Buchau**
 Session Chair: **Francis Piriou**

1:45pm - 3:25pm**Lounge****PB6: Novel computational methods for machines and devices 2**

Session Chair: **Nelson Sadowski**
 Session Chair: **Takashi Todaka**

3:25pm - 3:50pm**Coffee break****Lounge****3:50pm - 5:30pm****Room #0100****OA4: Wave propagation**

Session Chair: **Herbert De Gerssem**
 Session Chair: **Igor Tsukerman**

Date: Wednesday, 01/Jul/2015**8:30am - 10:10am****Room #0100****OA5: Novel computational methods for machines and devices**

Session Chair: **Piergiorgio Alotto**
 Session Chair: **Hartmut Brauer**

10:10am - 10:30am**Coffee break****Lounge****10:30am - 12:15pm****Cafeteria****PC1: Bio-electromagnetic computation**

Session Chair: **Walter Pereira Carpes Jr**
 Session Chair: **Nathan Ida**

10:30am - 12:15pm**Lounge****PC2: Multi-physics and coupled problems 1**

Session Chair: **Lionel Pichon**
 Session Chair: **Maurizio Repetto**

10:30am - 12:15pm**Lounge****PC3: Novel computational methods for machines and devices 3**

Session Chair: **Laurent Krähenbühl**
 Session Chair: **Jianguo (Joe) Zhu**

12:15pm - 1:45pm**Lunch****La Plaza****1:45pm - 3:25pm****Cafeteria****PC4: Numerical techniques 2**

Session Chair: **Chang-seop Koh**
 Session Chair: **Guglielmo Rubinacci**

1:45pm - 3:25pm**Lounge****PC5: Material modeling 2**

Session Chair: **Dennis D Giannacopoulos**
 Session Chair: **Frederic Sirois**

1:45pm - 3:25pm**Lounge****PC6: Nano-electromagnetic computation; Photonics and optoelectronics**

Session Chair: **Istvan Bardi**
 Session Chair: **Kurt Preis**

3:25pm - 3:50pm**Coffee break****Lounge****3:50pm - 5:30pm****Room #0100****OA6: Material modeling**

Session Chair: **Hajime Igarashi**
 Session Chair: **Ruth V. Sabariego**

6:30pm - 10:30pm**Montreal Science Center****Conference Dinner****Date: Thursday, 02/Jul/2015****8:30am - 10:10am****Room #0100****OA7: Numerical techniques**

Session Chair: **Anouar Belahcen**
 Session Chair: **Jan Sykulski**

10:10am - 10:30am**Coffee break****Lounge****10:30am - 12:15pm****Cafeteria****PD1: Electromagnetic compatibility**

Session Chair: **Jozsef Pavo**
 Session Chair: **Charles William Trowbridge**

10:30am - 12:15pm**Lounge****PD2: Optimization and design 3**

Session Chair: **Luiz Lebensztajn**
 Session Chair: **Guangzheng Ni**

10:30am - 12:15pm**Lounge****PD3: Numerical techniques 3**

Session Chair: **Alain Bossavit**
 Session Chair: **Wolfgang M. Rucker**

12:15pm - 1:45pm**Lunch****La Plaza****1:45pm - 3:25pm****Cafeteria****PD4: Wave propagation 2**

Session Chair: **Yasushi Kanai**
 Session Chair: **Ruben Specogna**

1:45pm - 3:25pm**Lounge**

1:45pm - 3:25pm	PD5: Multi-physics and coupled problems 2
Lounge	Session Chair: Stephane Brisset Session Chair: Dong-Hun Kim
3:25pm - 3:50pm	PD6: Novel computational methods for machines and devices 4
Lounge	Session Chair: Behzad Forghani Session Chair: Milica Popovich
3:50pm - 5:30pm	OA8: Multi-physics and coupled problems
Room #0100	Session Chair: Stephane Clenet Session Chair: Patrick Dular
5:30pm - 6:00pm	Closing: Closing session
Room #0100	Session Chair: David Lowther

Presentations

OA1: Overview

Time: Monday, 29/Jun/2015: 9:10am - 10:10am · *Location:* Leacock Bldg #132

Session Chair: David Lowther

Session Chair: Arnulf Kost

ID: 656 / OA1: 1

Track 10

Topics: Mathematical Modelling and Formulations, Multi-physics and Coupled Problems

Keywords: Magnetostatics, magnetic force, virtual power principle

Body forces and contact forces in assemblies of magnetized pieces of matter

Alain Bossavit

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When two magnets are stuck together, where do magnetic forces operate and which formulas should one apply to compute them? Such frequently asked questions do not find immediate answers in the literature on forces, mainly because the force field is obtained, by the Virtual Power Principle, as a (mathematical, vector-valued) \textsc{distribution,} not as a plain vector field, which would be more convenient for practical computation. We show here, in a few important cases (magnet in contact with magnetizable metal, two hard magnets in contact, etc.) how to represent this single distribution by two vector fields, one of them borne by the bulk of the matter, the other one localized at material interfaces where discontinuities of permeability, of magnetization, etc., do occur. A general approach is then suggested.

ID: 145 / OA1: 2

Track 04

Topics: Photonics and Optoelectronics, Multi-scale modelling and homogenization

Keywords: Electromagnetic metamaterials, high-order schemes, approximation methods, wave propagation, electrodynamic

Electromagnetic Homogenization: the Uncertainty Principle and Its Numerical Verification

Igor Tsukerman¹, Vadim A. Markel²

¹The University of Akron, United States of America; ²University of Pennsylvania, Philadelphia, United States of America;

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The effective permeability of electromagnetic metamaterials can deviate significantly from unity at high frequencies -- an intriguing property not available in natural materials. However, we show both analytically and numerically that this artificial magnetism has limitations: the stronger the magnetic response, the less accurate the homogenization. New computational aspects of the paper include high-order Trefftz difference schemes and highly accurate computation of Bloch modes on nonorthogonal grids, high-order absorbing boundary conditions, and numerical implementation of new Trefftz homogenization on rhombic lattices.

ID: 72 / OA1: 3

Track 16

Topics: Bio-Electromagnetic Computation

Keywords: Magnetic resonance imaging, Motion induced electric field, Electromagnetic human exposure, Finite element method

A potential-based formulation for motion-induced electric field in MRI

Oriano Bottauscio¹, Mario Chiampi², Luca Zilberti¹

¹Istituto Nazionale di Ricerca Metrologica, Torino, Italy; ²Politecnico di Torino, Italy; l.zilberti@inrim.it

This paper presents a potential-based formulation conceived to estimate the electric field induced in a human body which moves through the stray stationary magnetic field produced by magnetic resonance scanners. The formulation is written in the moving reference frame of the body and it is solved numerically, according to a time domain Finite Element approach. Both conduction and dielectric components of the induced currents are taken into account, allowing a discussion about the effect of tissue permittivity, which suffers a very high uncertainty at low frequency. Some examples of exposure assessment in realistic situations are finally presented.

PA1: Mathematical modeling and formulations 1

Time: Monday, 29/Jun/2015: 10:30am - 12:15pm · *Location:* Cafeteria

Session Chair: Szabolcs Gyimóthy

Session Chair: François Henrotte

ID: 263 / PA1: 1

Track 12

Topics: Static and Quasi-Static Fields, Mathematical Modelling and Formulations

Keywords: Nonlinear magnetics, Interpolation, Manifolds, Reduced order systems

Nonlinear Interpolation on Manifold of Reduced Order Models in Magnetodynamic Problems

Yannick Paquay, Olivier Bruls, Christophe Geuzaine

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Proper Orthogonal Decomposition (POD) is an efficient model order reduction technique for linear problems in computational sciences, recently gaining popularity in electromagnetics. However, its efficiency has been shown to considerably degrade for nonlinear problems. In this paper, we propose a reduced order model for nonlinear magnetodynamic problems by combining POD with an interpolation on manifolds, which interpolates the reduced bases to efficiently construct the desired solution.

ID: 49 / PA1: 2

Track 11

Topics: Mathematical Modelling and Formulations, Numerical Techniques

Keywords: cavity resonators, numerical simulation

Computation of External Quality Factors for RF Structures by Means of Model Order Reduction and a Perturbation Approach

Thomas Flisgen, Johann Heller, Ursula van Rienen

University of Rostock, Germany; thomas.flisgen@uni-rostock.de

External quality factors are significant quantities to describe losses via waveguide ports in radio frequency resonators. The current contribution presents a novel approach to determine external quality factors by means of a two-step procedure: First, a state-space model for the lossless radio frequency structure is generated and its model order is reduced. Subsequently, a perturbation method is applied on the reduced model, so that external losses are accounted for. The advantage of this approach results from the fact that the challenges in dealing with lossy systems are shifted to the reduced order model. This significantly saves computational costs. The paper provides a short overview on existing methods to compute external quality factors. Then, the novel approach is introduced and validated in terms of accuracy and computational time by means of commercial software.

ID: 64 / PA1: 3

Track 05

Topics: Mathematical Modelling and Formulations

Keywords: Volume Integral Equation, Dielectric materials, Unstructured-PEEC, Magneto-harmonic

Volume Integral Formulation Using Facet Elements For Electromagnetic Problem Considering Conductors And Dielectrics

Jonathan Siau^{1,2,3}, Gérard Meunier^{2,3}, Olivier Chadebec^{2,3}, Jean-Michel Guichon^{2,3}, Rémy Perrin-Bit¹

¹CEDRAT S.A., Grenoble, France; ²Univ. Grenoble Alpes, G2Elab, F-38000 Grenoble, France; ³CNRS, G2Elab, F-38000 Grenoble, France; jonathan.siau@cedrat.com

A new integral formulation is presented, enabling the computation of resistive, inductive and capacitive effects considering both conductors and dielectrics in the frequency-domain. The considered application here allows us to neglect any propagation effects and magnetic materials. In this paper, we will show how to improve the unstructured-PEEC (U-PEEC) approach to consider dielectric materials, keeping the same benefits. Results obtained with this formulation are compared to experimental data.

ID: 60 / PA1: 4

Track 15

Topics: Static and Quasi-Static Fields, Mathematical Modelling and Formulations, Numerical Techniques, Novel Computational Methods for Machines and Devices

Keywords: Reluctance network, Finite Element Method(FEM), face shape functions, Face FEM

Magnetic devices analysis by Face FEM coupled with standard reluctance network

Anderson Santos Nunes^{1,4}, Olivier Chadebec^{2,3}, Gerard Meunier^{2,3}, Patrick Kuo-Peng⁴

¹ESSS - Engineering Simulation & Scientific Software; ²Univ. Grenoble Alpes - G2Elab; ³CNRS - G2Elab; ⁴UFSC - Universidade Federal de Santa Catarina, Florianópolis - GRUCAD; anderson@esss.com.br

A Finite Element Method (FEM) mesh is converted to a reluctance network through an original magnetostatic formulation based on face shape functions. This meshed reluctance network is coupled with an standard one, characterizing a 0D system. Both approaches are fully-compatible and the hybridized problem can be solve with a single circuit solver. The approach is tested in 2D on a magnetic circuit with an air gap and compared to classical

FEM nodal formulation.

ID: 92 / PA1: 5

Track 13

Topics: Static and Quasi-Static Fields, Optimization and Design, Mathematical Modelling and Formulations, Numerical Techniques

Keywords: Optimization, Magnetostatics, Fusion Reactor Design

A Combinatorial Approach to Shape Optimization of High Field Magnets

Andrea G. Chiariello, Alessandro Formisano, Francesco Ledda, Raffaele Martone, Francesco Pizzo

Seconda Università degli Studi di Napoli, Italy; francesco.pizzo@unina2.it

The shape optimization of magnets can be very demanding because of the number of field map evaluations required especially when a high accuracy is needed. Here, in the limits of linearity assumption, a new approach is proposed based on the projection of the coil geometry in a finite dimension functional basis. Then the associated Green functions can be computed in advance and any possible solution can be examined just by combining a suitable set of elementary contributes. The advantage in computing burden and accuracy is assessed in the case of challenging magnets for Tokamak devices.

ID: 132 / PA1: 6

Track 19

Topics: Optimization and Design, Mathematical Modelling and Formulations

Keywords: High Field Magnets, Inverse Problems, Magnetostatic

Field Map Characterization from Magnetic Survey in High Field Magnets

Alessandro Formisano, Raffaele Martone

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Quality checks to characterize magnets before final assembly are usually foreseen when high accuracy is required in magnetic field maps. This process may possibly include magnetic field measurements in regions adjacent to the coils, thus different from the target field areas. This technique implies inverse problem approaches to estimate coils deformation parameters, and resulting accuracy may be poor due to ill conditioning of underlying mathematical processing. To counteract such drawback, suited measures are usually taken, but attention is given to estimating parameters regardless of their use. In this paper, a discussion is presented about characteristics of the inverse problem relating magnetic field and deformation parameters and about the actual accuracy needs when the interest is focused on magnetic field map in target areas rather than on parameters themselves.

ID: 202 / PA1: 7

Track 11

Topics: Mathematical Modelling and Formulations, Numerical Techniques

Keywords: Maxwell equations, low-frequency, frequency domain, multi-query, robust formulation

Low-Frequency Stabilization for Maxwell's Equations and Applications using Reduced Order Modeling

Martin Eller^{1,2,3}, Stefan Reitzinger³, Sebastian Schöps^{1,2}, Sabine Zaglmayr³

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The simulation of possibly electrically large devices require in many applications robust solutions from DC to high frequencies. For this purpose we introduce a symmetric low-frequency stable formulation of Maxwell's equations which allows the simulations of electrically large structures down to DC. It is discretized in space by the finite element method. The numerical complexity, in particular in multi-query scenarios, is decreased by employing a Reduced Order Modeling method allowing for efficient computations.

ID: 236 / PA1: 8

Track 04

Topics: Static and Quasi-Static Fields, Mathematical Modelling and Formulations, Numerical Techniques

Keywords: fully computable error bounds, hypercircle method, one stroke complementarity, explicit flux equilibration, adaptive stopping criterion

Lean complementarity for Poisson problems

Ruben Specogna

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We introduce a novel technique—lean complementarity—that eliminates any waste of computational resources occurring during the pursuing of complementarity. First, it requires the solution of the scalar potential formulation only, since flux equilibration is performed explicitly, i.e. without solving any linear system. Second, the systems arising during adaptive mesh refinement are solved inexactly on purpose, by stopping the iterations of the iterative solver when the algebraic error gets negligible with respect to the estimated discretization error. Discretization error is estimated with complementarity, whereas the algebraic error is computed very accurately with a novel and cheap technique.

ID: 286 / PA1: 9

Track 15

Topics: Static and Quasi-Static Fields, Mathematical Modelling and Formulations, Novel Computational Methods for Machines and Devices

Keywords: Electromagnetic modeling, electromagnetic analysis, magnetic circuits, performance evaluation, Maxwell equations, finite element analysis, Magnetic saturation

Consideration of Magnetic Saturation in a New Hybrid Semi-Numerical Model

Sofiane OUAGUED, AbdouRahman ADEN DIRIYE, Yacine AMARA, Georges BARAKAT

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The aim of this paper is first to briefly describe a mathematical approach for the direct coupling between analytical formal solution of Maxwell's equations (AM) and magnetic equivalent circuits (MEC) (reluctance networks or permeance networks) methods for the electromagnetic modeling of electric machines. This coupling can help solve the problem of air-gap modeling in MEC method, and the consideration of the local magnetic saturation in modeling approaches involving analytical formal solution of Maxwell's equations. The formal solution of Maxwell's equations is obtained by using separation of variable method along with Fourier series analysis; it is used to model constant permeability regions (magnetic air-gap). The MEC method is used to model regions which include ferromagnetic parts. MEC model is generated based on a mesh of the studied domain. Different approaches related to the consideration of magnetic saturation are investigated and compared.

ID: 348 / PA1: 10

Track 04

Topics: Mathematical Modelling and Formulations, Numerical Techniques*Keywords:* Reduced-order models, proper orthogonal decomposition, full wave, capacitive effects, finite-element methods**Reduced order model for accounting for high frequency effects in power electronic components****Yannick Paquay², Christophe Geuzaine², Md. Rokibul Hasan¹, Ruth V. Sabariego¹**¹KU Leuven, Belgium; ²University of Liege, Belgium; ruth.sabariego@esat.kuleuven.be

This paper proposes a reduced-order model of power electronic components based on the proper orthogonal decomposition. Starting from a full-wave finite-element model and several snapshots/frequencies, the reduced order model is constructed. The characteristic complex impedance can then be extrapolated for the intermediate frequencies with a very low computational cost.

ID: 344 / PA1: 11

Track 14

Topics: Static and Quasi-Static Fields, Numerical Techniques*Keywords:* Finite element analysis, principal component analysis, reduced order system.**Adaptive Subdomain Model Order Reduction with Discrete Empirical Interpolation Method for Nonlinear Magneto-Quasi-Static Problems****Yuki Sato¹, Markus Clemens², Hajime Igarashi¹**¹Hokkaido University, Japan; ²Bergische Universität Wuppertal, Germany; yukisato@em-si.eng.hokudai.ac.jp

This paper presents a novel adaptive subdomain model order reduction (MOR) based on proper orthogonal decomposition (POD) and discrete empirical interpolation (DEI) methods for nonlinear magneto-quasi-static (MQS) problems. In this method, the nonlinear region is subdivided into two regions where one of region includes all those finite elements which have particularly strong saturation in the nonlinear material and the other region does not. MOR based on POD and DEI methods is applied only to the latter region. Both regions are determined from the previous solution automatically because the finite elements which have the strong nonlinearity in the ferromagnetic material may change at each time step. It is shown that this method can effectively reduce the computational time to solve the nonlinear MQS problems without losing quality of accuracy in comparison with the accuracy of the non-reduced finite element method.

ID: 192 / PA1: 12

Track 05

Topics: Mathematical Modelling and Formulations*Keywords:* Current Source, Finite Element, Induction Machine, Magnetic Vector Potential, Movement**Computation of Source for Non-Meshed Coils in a Reduced Domain with A-V Formulation****Pauline Ferrouillat^{1,2,3}, Christophe Guérin³, Gérard Meunier^{1,2}, Brahim Ramdane^{1,2}, Patrick Dular⁴, Patrice Labie^{1,2}, Delphine Dupuy³**¹Univ. Grenoble Alpes, G2Elab, Grenoble, France; ²CNRS, G2Elab, Grenoble, France; ³CEDRAT, Meylan, France; ⁴University of Liège, Liège, Belgium; pauline.ferrouillat@g2elab.grenoble-inp.fr

The discretized source magnetic vector potential \mathbf{A}_j , interpolated from source field \mathbf{H}_s with $\mathbf{H}(\text{curl}, \Omega)$ semi-norm, is studied for non-meshed coils with magnetic vector potential \mathbf{A} and electric scalar potential V formulation. As a novelty, source potential \mathbf{A}_j is computed in a reduced domain Ω_{red} instead of the complete domain Ω . For domains with fixed and moving parts, potential \mathbf{A}_j can be computed on each part, for each of the related current sources, with no need to ensure its continuity between these parts.

PA2: Wave propagation 1

Time: Monday, 29/Jun/2015: 10:30am - 12:15pm · *Location:* Lounge

Session Chair: Zhuoxiang Ren

Session Chair: Jon Webb

ID: 15 / PA2: 1

Track 20

Topics: Wave Propagation, Numerical Techniques

Keywords: Wave propagation, wave scattering, Trefftz approximations, nonreflecting boundary conditions

Trefftz Approximations: A New Framework for Nonreflecting Boundary Conditions

Igor Tsukerman¹, Ralf Hiptmair²

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A new general framework for nonreflecting boundary conditions in wave scattering involves a set of local Trefftz functions – outgoing waves – and a commensurate set of degrees of freedom (dof). With specific choices of bases and dof, one obtains classical Engquist-Majda and Bayliss-Turkel conditions. Other choices yield a variety of nonreflecting conditions. With additional dof on the artificial nonreflecting boundary, the accuracy of the numerical solution can approach machine precision even on fairly coarse grids, as illustrated numerically.

ID: 45 / PA2: 2

Track 20

Topics: Wave Propagation

Keywords: Computational electromagnetics, electromagnetic propagation, finite difference methods, radar cross-sections

An Enhanced Total-Field/Scattered-Field Scheme for the 3-D Nonstandard Finite-Difference Time-Domain Method

Tadao Ohtani¹, Yasushi Kanai², Nikolaos V. Kantartzis³

¹Asahikawa City; ²Niigata Institute of Technology, Japan; ³Aristotle University of Thessaloniki; kanai@iee.niit.ac.jp

The nonstandard (NS)-FDTD method exhibits high accuracy at fixed frequencies and thus proven to be a powerful means for the radar cross section (RCS) analysis of scattering objects with complicated geometries. Toward this aim, significant enhancement can be pursued in the combination with the FDTD total-field/scattered-field (TF/SF) concept. However, the principal implementation characteristics of the latter in the NS-FDTD technique have not been yet elaborately studied, especially for electrically large domains or structures. Thus, in this paper, a new advanced TF/SF scheme for the 3-D NS-FDTD algorithm is developed and fully investigated. Numerical results reveal that the proposed method, considering the features of the NS-FDTD operators, is far more efficient and versatile than the original FDTD one.

ID: 80 / PA2: 3

Track 18

Topics: Wave Propagation, Nano-Electromagnetic Computation, Numerical Techniques, Photonics and Optoelectronics

Keywords: Plasmons, Coupled Mode Analysis, Metal-Insulator Structures, Optical Waveguides

Coupled Mode Analysis of Metal-Insulator-Metal Waveguide

Tomotaka Ikeda¹, Toshiaki Kitamura², Kiyoshi Kishioka³

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Surface plasmon polaritons (SPPs) have attracted much interest due to their ability to manipulate light at a subwavelength scale. Planar SPP devices mainly consist of two types of configurations, metal-insulator-metal (MIM) and insulator-metal-insulator (IMI). In this study, the coupling coefficients of two parallel MIM waveguides are analyzed utilizing the coupled-mode equations. The frequency characteristics of the power transmittance of a MIM waveguide coupled with a resonant cavity are also studied and compared with the simulation results. The simulations are carried out by using the FDTD method into which motion equations of free electrons are installed.

ID: 89 / PA2: 4

Track 05

Topics: Wave Propagation, Numerical Techniques

Keywords: Differential forms, Medium changes, Hodge matrix.

Hybrid-Hodge Matrix

Alex Sander de Moura¹, Elson José da Silva², Werley Gomes Facco³, Rodney Rezende Saldanha², Ricardo Luiz da Silva Adriano²

¹UFJF, Brazil; ²UFMG, Brazil; ³IFES, Brazil; alex.moura@ufjf.edu.br

By applying the theory of differential forms to solve problems of wave propagation, we must solve sparse linear system defined by the insertion of constitutive laws through Hodge matrix. In this article we use two techniques of construction of the Hodge matrix, namely, the Galerkin method and Yee method. These techniques are used to construct a hybrid matrix having the best of both techniques for the treatment of medium changes. Numerical results will be presented to showed the performance of approaches to solve static problems in two-dimensional spaces.

ID: 101 / PA2: 5

Track 01

Topics: Wave Propagation, Optimization and Design

Keywords: Dielectric Effective Permittivity, Equivalent Circuit Model, Frequency Selective Surfaces, Particle Swarm Optimization.

Particle Swarm Optimization of Square Loop Frequency Selective Surfaces considering a Model of Dielectric Effective Permittivity

MARIO ALBERTO RODRIGUEZ¹, WALTER CARPES JR²

¹UNIVERSIDAD DISTRITAL FRANCISCO JOSE DE CALDAS, Colombia; ²UNIVERSIDADE FEDERAL DE SANTA CATARINA, Brazil; marodriguezba4@gmail.com

This paper presents the results of a Particle Swarm Optimization Method (PSO) applied in the design of a square loop frequency selective surface (FSS) via the Equivalent Circuit Model (ECM). In the optimization process, besides the FSS geometrical parameters, the thickness and relative permittivity of dielectric material used as support are included as variables in the search space. The effect of dielectric layers is considered in the ECM by using a model of dielectric effective permittivity for square loop FSS developed for us in a previous work. Square loop FSS are synthesized and the obtained results are compared with designs reported in literature. PSO method results were implemented with ECM and compared with Ansoft HFSS commercial software simulations.

ID: 140 / PA2: 6

Track 11

Topics: Wave Propagation, Numerical Techniques

Keywords: Discrete Geometric Approach, Waveguide, Modal Excitation, Port boundary condition.

Excitation by scattering/total field decomposition and UPML in the geometric formulation

Matteo Cicuttin¹, Lorenzo Codecasa², Ruben Specogna¹, Francesco Trevisan¹

¹University of Udine, Italy; ²Politecnico di Milano, Italy; matteo.cicuttin@uniud.it

The paper presents a general technique to apply excitations in the framework of discrete geometric numerical methods using dual grids, like DGA and FIT.

ID: 218 / PA2: 7

Track 19

Topics: Wave Propagation, Numerical Techniques

Keywords: High performance computing, Microwave simulation, Finite-difference time domain (FDTD) method, Dedicated computer, Dataflow architecture, Field programmable gate array (FPGA)

Improved Architecture of FDTD Dataflow Machine

Hideki Kawaguchi

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As one of solutions to a portable high performance computing (HPC) technologies for microwave simulations, several kinds of dedicated computer for the finite-difference time-domain (FDTD) method has been considered. However, it was necessary to implement the dedicated computer on a reconfigurable LSI such as the field-programmable gate array (FPGA) in principle, therefore, the LSI clock cycle was 100 MHz at most and it was very difficult to exceed performance of high-end PCs and GPU computers as well. Then, a dataflow architecture FDTD dedicated computer, in which the highly parallel property hidden in the FDTD scheme is implemented, was proposed and it was shown that the estimated performance of the dataflow machine can exceed those of the high-end PC and GPU computers. On the other hand, the digital circuit of the dataflow machine was inefficiently implemented on the FPGA owing to dual operation modes of a normal FDTD grid and PML grid, that is, almost half part of FPGA was not used in the most cases. This paper proposes an improved FDTD dedicated circuit with the dual operation modes to avoid the inefficient implementation.

ID: 327 / PA2: 8

Track 01

Topics: Wave Propagation

Keywords: Topology optimization, normalized Gaussian network (NGnet), FDTD method, energy harvesting

Topology Optimization of Self-Complementary Antenna for Microwave Energy Harvesters

Takuya Mori, Hajime Igarashi

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This paper presents topology optimization of self-complementary antennas (SCA) for microwave energy harvesters for wireless sensors. The antenna shapes are optimized to maximize isotropic gain and reduce return loss in a given frequency band using the micro genetic algorithm and FDTD computation. For the topology optimization, we employ the normalized Gaussian network. The self-complementary antenna is realized by considering its spatial symmetries into account. It is shown that the actual gain of the optimized SCA is more than 5dBi from 2.0GHz to 3.0GHz.

ID: 335 / PA2: 9

Track 04

Topics: Wave Propagation

Keywords: Finite integration method, perfectly matched layer absorbing boundary, space-time grid, subgrid

Space-time Grid Connections for Finite Integration Method

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The perfectly matched layer (PML) absorbing boundary is implemented for the space-time finite integration (FI) method. The subgrid connection in 3D and 4D space-time is discussed. The computational accuracy of several types of 3D and 4D space-time subgrid methods are evaluated using the PML.

ID: 433 / PA2: 10

Track 18

Topics: Wave Propagation, Mathematical Modelling and Formulations, Numerical Techniques

Keywords: Finite element analysis, adaptive techniques, FEM, FDM, FDTD

Higher-order adaptivity techniques for modeling fast transients on high-voltage lines

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Adaptive techniques for modeling fast transient on high-voltage lines are proposed and evaluated. These techniques seem to be a powerful tool for higher-order finite element analysis of these phenomena, bringing considerable savings both in memory and time of computation. A typical example is presented showing the advantage of this approach.

ID: 467 / PA2: 11

Track 07

Topics: Wave Propagation

Keywords: Ultra wideband filter, Wireless LAN, Harmonic band, CRLH-TL, Step impedance, Spurline, Particle swarm optimization, Ripple, Improved PSO

Optimal Design of a Compact filter for UWB applications using an Improved Particle Swarm Optimization

Seung-Hun Oh¹, SeungJae Lee¹, Sungtek Kahng², Kyung Choi³, Hyeong-Seok Kim¹

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This paper uses an improved particle swarm optimization (PSO) to design a novel compact ultra wideband (UWB) filter. The filter consists of an only one-cell composite right and left handed-transmission line (CRLH-TL) resonator, stepped impedance (SI), and two spurlines. The one-cell CRLH-TL resonator has a compact size and forms a wide passband. An SI and two spurlines are employed to reject both the harmonics out of the UWB and the wireless local area network (WLAN, 5.15-5.825GHz) band. In order to optimize efficiently the filter, the design of the proposed filter is performed by an improved PSO. During the improved PSO, the objective function converges from the 96th iteration. And the characteristic of the filter is optimized as acceptable results. The proposed filter has the overall size of 14 x 15mm²(0.63λ_g x 0.53λ_g), a bandwidth of 105% for a return loss > 10 dB, an insertion loss < 0.98dB, and stopbands at 11.5~22GHz and WLAN band. In particular, the ripple in the passband is minimized by the improved PSO.

ID: 520 / PA2: 12

Track 20

Topics: Wave Propagation, Numerical Techniques

Keywords: Electromagnetic propagation, Waveguide bends, Maxwell equations, Time-domain analysis

Interpolating Moving Least-Squares-Based Meshless Time-Domain Method for Stable Simulation of Electromagnetic Wave Propagation in Complex Shaped Domain

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To stabilize the electromagnetic wave propagation simulations using a meshless time-domain method~(MTDM) in complex shaped domains, the new MTDM embedding the shape functions generated by the interpolating moving least-squares method~(IMLS) has been developed. Numerical experiments show that the new MTDM can employ a relatively large time step for the simulations in comparison with that of the conventional one. In addition, the parameters for generating shape functions of new MTDM can be chosen more flexibly than those of the conventional one.

ID: 612 / PA2: 13

Track 20

Topics: Wave Propagation, Numerical Techniques

Keywords: Eigenvalues and Eigenfunctions, Finite Difference Methods, Numerical Simulation

A Study on Non-Linear Eigenvalue Problems for Waveguide-Coupled Electromagnetic Cavities

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The frequency domain simulation of electromagnetic resonators with finite methods (Finite Elements, Finite Integration) leads to large-scale eigenvalue formulations. Any kind of loss mechanism, such as conduction or radiation through open ports of the structure, necessarily corresponds to complex eigenvalues, where the ratio of the real and imaginary parts of the eigenvalues defines the (internal and/or external) Q-values of the modes. In the case of an external coupling to waveguides with dispersion characteristics the eigenvalue formulation becomes non-linear, i.e. the system matrix depends on the eigenfrequency to be computed. We use an integral solver for such non-linear eigenvalue problems and perform a study on some varying formulations. Some important properties are discussed such as the spectral properties, the influence of some approximations therein, as well as the efficiency of the overall solution process.

ID: 290 / PA2: 14

Track 19

Topics: Wave Propagation, Mathematical Modelling and Formulations, Numerical Techniques

Keywords: Computational electromagnetics, Finite volume methods, Surface impedance, Linear particle accelerator

SIBC Formulation for a Low-Dispersion Finite Volume Method in the Time Domain

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Surface Impedance Boundary Conditions (SIBC) for the computation of resistive wall wakefields in linear accelerators are developed. The method extends the Staggered Finite Volume Method in the Time Domain (SFVTD) for the discretization of Maxwell's equations. It uses an Auxiliary Differential Equation (ADE) formulation for general impedance functions describing frequency dependent wall conductivity, surface roughness or metal oxidation. For the time discretization of the resulting dispersive equations a particular technique based on exponential integration is employed. This allows to preserve the basic properties of the SFVTD method such as low numerical dispersion and optimal stability bound which are of crucial importance for electromagnetic wakefield computations.

ID: 231 / PA2: 15

Track 02

Topics: Wave Propagation, Electromagnetic Sensors, Sensing and Metrology

Keywords: adaptive back-projection, electromagnetic wave, microwave imaging, range migration, synthetic aperture radar

Hybrid Method combining RMT and ABP Algorithm for Microwave Imaging

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Microwave imaging is a technique aimed at sensing a given region by means of interrogating electromagnetic waves. In practice, the range migration technique (RMT) as a kind of synthetic aperture radar (SAR) imaging algorithm has a high computational efficiency and accuracy in reconstruction. However, this approach involves a frequency domain interpolation, which may adversely affect the accuracy of image reconstruction. The back-projection (BP) algorithm originated from medical imaging techniques achieves fine reconstructed images because it avoids frequency domain interpolation, but usually has a huge computational cost. To overcome these disadvantages, this paper proposes the hybrid method combining RMT and adaptive BP (ABP) algorithm for reconstruction with high-quality. Then, simulated and experimental data are obtained to validate the performance of the proposed algorithm.

PA3: Novel computational methods for machines and devices 1

Time: Monday, 29/Jun/2015: 10:30am - 12:15pm · *Location:* Lounge

Session Chair: Claude Marchand

Session Chair: Erich Schmidt

ID: 19 / PA3: 1

Track 17

Topics: Novel Computational Methods for Machines and Devices

Keywords: Equivalent magnetic material (EMM), 2-D conversion analysis, 3-D flux machine, Non-uniform height and material.

A Novel Conversion Analysis for 3-dimensional Machine with Non-uniform Height and Material

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This paper presents a novel analysis method for a 3-dimensional (3-D) flux machine. 2-dimensional (2-D) conversion method is proposed to take into account the 3-D structure which has non-uniform height and material according to the stack length. In the proposed 2-D model, virtual material which is expressed by the permeability and relative stack length of the corresponding materials is generated. Various magnetic characteristics are calculated and the correctness and usefulness of the proposed method are verified by using 3-D analysis.

ID: 36 / PA3: 2

Track 16

Topics: Novel Computational Methods for Machines and Devices

Keywords: Wavelet Neural Networks, Finite Element Analysis, State Space Models, Microgrid High Speed Generators.

EM-SS-Wavelets for Characterization of High-Speed Generators in Distributed Generation

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An Electromagnetic-State Space-Wavelet Neural Network, EM-SS-WNN, modeling environment is presented and used for characterization of high-speed synchronous generators during out of phase operation in Microgrids. This mode of operation may result in stresses in the network or the failure of the high-speed generators. The approach is validated, by comparing simulation results to test data, in a case study involving two out of phase high-speed generators. In addition, the effectiveness of the EM-SS-WNN approach is demonstrated in terms of accuracy and fast response.

ID: 50 / PA3: 3

Track 17

Topics: Optimization and Design, Novel Computational Methods for Machines and Devices

Keywords: Electromagnetic analysis, Finite element analysis, Magnetic flux, Magnetic forces

Efficient Reluctance Network Model for Modelling, Design and Optimization of Linear Switched Reluctance Motor by

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In this paper, we propose an efficient reluctance network for modeling a linear switched reluctance motor. The proposed reluctance network model takes an account the magnetic characteristic and the flux leakage. Consequently, the proposed model, compared with finite element method, gives precise results of the electromagnetic characteristic. The proposed variable reluctance network developed is able to be coupled with other tools in aim to optimize the linear machine

ID: 68 / PA3: 4

Track 06

Topics: Electromagnetic Sensors, Sensing and Metrology, Novel Computational Methods for Machines and Devices

Keywords: Electric machines, Finite Element Method, Magnetic Sensors, Electromagnetic Modeling, Fault Detection

Synchronous Generator Fault Investigation by Experimental and Finite Element Procedures

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Finite Element calculations and experimental measurements are employed in this work to detect faults in synchronous generators. A special benchmark constructed to this study allows to impose several controlled defects as short-circuits in the rotor filed winding, short-circuited stator turns, rotor eccentricities as well as short-circuits on the stator core iron sheets. The air-gap magnetic field can be detected by means of sensors inside de machine and is also calculated by the FEM.

ID: 151 / PA3: 5

Track 09

Topics: Optimization and Design, Mathematical Modelling and Formulations

Keywords: Energy method, finite element method(FEM), Halbach PM arrays, linear magnetic gear, magnetic circuit

Analysis of Magnetic Field and Force in a Tubular Linear Magnetic Gear with Halbach PM Arrays

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This paper proposes a tubular linear magnetic gear installed with Halbach arrayed permanent magnets(TLMGHM). Based on the principle of magnetic permeability modulation, the formulations for the transmitting force which reflects the main transmitting capability

of TLMG are theoretically deduced from the energy method. In order to produce positive force, the steady working point of TLMG is predetermined elaborately. Features of forces on low-speed and high-speed side are analyzed. Analysis results show that the TLMGHM can offer higher thrust force and lower ripple than tubular linear magnetic gear with radially permanent magnets(TLMGRM).

ID: 164 / PA3: 6

Track 13

Topics: Novel Computational Methods for Machines and Devices

Keywords: level set, design optimization, electromagnetic devices

Level-Set Based Topology Optimization Using Remeshing Techniques for Magnetic Actuator Design

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A level-set based topology optimization method for the optimal design of magnetic devices has been successfully applied due to its clear boundary expression compared to the element based topology optimization method [1]. Since the conventional level-set method is based on the Eulerian concept in which the meshes for analysis are fixed in the design domain, the level-set boundaries of the structure cannot be precisely represented by finite elements, resulting in a decrease in the accuracy of analysis. In electromagnetic fields, it is very important to consider the exact material boundaries since the magnetic force for the actuator design is calculated by integrating Maxwell's stress tensor over the exterior surfaces of structure [2]-[3]. To overcome this problem, remeshing techniques such as the adaptive mesh method [4] and the extended finite element method (XFEM) [5] are considered in order to modify the structural boundaries more effectively.

This paper proposes a new level-set based topology optimization method for the optimal design of magnetic devices by employing two remeshing techniques that are able to consider the first-order triangular and the quadrilateral elements, respectively. The mesh coincides with the material boundaries by tracking the zero level-set and re-generating the finite elements during the optimization process. A modified adaptive remeshing technique for the triangular elements is proposed to control the level of mesh density by introducing a resolution parameter that can regulate the number of boundary points. To update the level-set functions after remeshing, a linear interpolation scheme is applied to the triangular elements and the homography estimation method used in image processing [6] is employed for the quadrilateral elements. To verify the effectiveness of the proposed method, it is applied to an electromagnetic problem of a C-core actuator that is very sensitive to structural boundaries.

ID: 175 / PA3: 7

Track 09

Topics: Numerical Techniques, Material Modelling, Novel Computational Methods for Machines and Devices

Keywords: Actuators, Finite element analysis, Magnetic hysteresis, Soft magnetic materials

Magnetic Field Analysis of Self-propelled Rotary Actuator's Stator by using Vector Magnetic Property Utilization Technique

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In this paper, in order to improve the self-propelled rotary actuator whose rotational axis is parallel to the exciting magnetic field, the magnetic field analysis of the actuator's stator is carried out. The actuator's stator is constructed from silicon steel sheets, the rolling direction of the silicon steel sheet can be taken into consideration in magnetic field analysis by using the complex E&S model which is one of the vector magnetic property utilization technique. The rotational magnetic flux has occurred in the silicon steel stator when a magnetic field is applied to the direction different from the rolling direction. It is expected that the rotational magnetic flux which occurs in the silicon steel stator contributes to rotate the rotor smoothly. Consequently, we estimate the suitable setting direction of the rolling direction in the actuator's silicon steel stator by this analysis.

ID: 254 / PA3: 8

Track 13

Topics: Optimization and Design, Multi-physics and Coupled Problems

Keywords: Finite element analysis, optimization, permanent magnet machines, soft magnetic materials, thermal analysis

Multidisciplinary Design Optimization of PM Machines with Soft Magnetic Composite Cores for Batch Production

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This paper presents a multidisciplinary design optimization (MDO) method for permanent magnet (PM) machines with soft magnetic composite (SMC) cores. Then a robust multiobjective optimization approach based on MDO is presented for these PM-SMC motors to achieve high manufacturing quality in batch production. The MDO analysis process mainly includes electromagnetic analysis, thermal analysis and modal analysis. Finally, to demonstrate the effectiveness of the proposed method, a PM transverse flux machine with SMC core is investigated to minimize the material cost and maximize the output power under several constraints from multidisciplinary design, such as temperature rise and motor efficiency. As shown, the proposed robust multiobjective MDO method can increase the reliability of all Pareto schemes significantly. And this obtained robust Pareto solution will benefit the batch production of PM-SMC motors.

ID: 270 / PA3: 9

Track 11

Topics: Material Modelling, Multi-physics and Coupled Problems

Keywords: Anisotropy, iron-loss, shrink-fitting, stress

Effect of Static Stress on Iron Loss in a Synchronous Reluctance Machine

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This study deals with the effect of static stress due to shrink-fitting and centrifugal force on the field computation and the iron losses of the electrical machines. The concept of stress induced magnetic anisotropy has been presented and implemented in a synchronous

reluctance machine model. A stress dependent iron-loss model with experimentally determined loss parameters has been implemented as well. The difference in flux density and finally the losses with and without stress dependency has been analyzed.

ID: 312 / PA3: 10

Track 18

Topics: Optimization and Design, Mathematical Modelling and Formulations

Keywords: partial element equivalent circuit (PEEC), resonant frequency, transmission parameter, wireless power transfer (WPT)

Modeling of Wireless Power Transfer Cell With Planar Circular Spiral Structure

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Wireless power transfer (WPT) technique based on magnetic resonant coupling has become a topical issue for academicians as well as engineers since it was reported by a research group of Massachusetts Institute of Technology (MIT). In this paper, a model based on partial element equivalent circuit is built to calculate the characteristics of a WPT cell with planar circular spiral structure. The track of one turn in WPT coil is modeled as a complete ring carrying constant current, and the mutual inductances and the parasitic capacitances among different turns are considered. The self-inductances and mutual inductances between various rings are calculated by Neumann's integral. Then, the resonant frequency and transmission parameter (S_{21}) of WPT cell are calculated and measured, and the results show the modeling method has a better accuracy.

ID: 337 / PA3: 11

Track 07

Topics: Optimization and Design

Keywords: Brushless Motors, Design Optimization, Electric Machines, Finite Element Analysis, Torque

Search Region Management Method for Local Search Algorithm employing Design Optimization of Brushless DC Motor

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Optimal design of electric machine such as motor requires much computation time since it is performed through Finite Element Analysis for higher accuracy. For this reason, development of optimization algorithm is regarded as a requisite in order to reduce the number of objective function calls. In case of Mesh Adaptive Direct Search (MADS) is the local search algorithm, so it is not guaranteed whether global optimum solution can be searched effectively, or not. Therefore, in this study, we introduce the novel optimization algorithm, History Management Method (HMM), to improve MADS. HMM uses a Guided Random Bit Generation based on gray-code as region selection when MADS iterates optimum search process for multi-start. The design variables are divided into appropriate rate and they are set to the region. In addition, during every iteration process of MADS, the information of previous searched points are saved and managed to increase an effectiveness of MADS. The proposed algorithm has been applied to brushless DC motor design optimization based on Finite Element Analysis.

ID: 351 / PA3: 12

Track 12

Topics: Mathematical Modelling and Formulations, Novel Computational Methods for Machines and Devices

Keywords: Finite Element analysis, Monte Carlo method, polynomial chaos expansion, stochastic process

Stochastic Approach to Estimate Interlaminar Losses of Electrical Sheets

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Random galvanic contacts are formed between the edges of the electrical contacts sheets when punched and pressed. In this paper, finite element formulation is introduced with a suitable boundary condition to account for these interlaminar contacts. The spatial variation of the conductivity at the edges of these electrical sheets is discretised using the Karhunen-Loeve expansion and propagated through the finite element formulation. The response to be obtained is approximated using polynomial chaos expansion. Then, the additional losses due to the interlaminar contacts are estimated from the solution obtained from different stochastic methods.

ID: 372 / PA3: 13

Track 09

Topics: Numerical Techniques

Keywords: Cage induction machine, eccentricity, electromagnetic torque, finite element method, power balance, rotordynamics

Numerical Analysis of the Power Balance of an Electrical Machine With Rotor Eccentricity

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The power balance in a cage induction machine with eccentric rotor has been studied. The asymmetrical air gap flux-density distribution caused by the non-uniform air gap due to eccentricity produces forces that play an important role in the rotordynamic stability. These forces act both in the radial and the tangential directions. The forces together with the whirling motion produce additional power in the shaft. It is shown that if the power balance of the machine is satisfied, the power due to the whirling can be calculated from the power balance. This also gives a new approach to compute the forces due to eccentricity.

ID: 405 / PA3: 14

Track 09

Topics: Material Modelling, Novel Computational Methods for Machines and Devices

Keywords: Electrical steel sheet, magnetostriction, magnetostriction forces, transformer

Finite Element Analysis of Magnetostriction Force in Power Transformer Based on the Measurement of Anisotropic Magnetostriction of a Highly Grain-Oriented Electrical Steel Sheet

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This paper presents a dynamic model of 2-D magnetostriction in electrical steel sheet (ESS) under rotating flux magnetization conditions and its implementation in finite element method (FEM). For an arbitrary waveform of magnetic flux density (B), the corresponding magnetostriction waveform can be predicted by the model. In order to apply the model to FEM easily, the model is based on trilinear interpolation method. As an example, the model is applied to a three-phase transformer constructed by highly grain-oriented electrical steel sheets and the numerical results by the magnetostriction model are discussed.

ID: 443 / PA3: 15

Track 01

Topics: Optimization and Design

Keywords: Optimization, Transformer design, Metaheuristics, Wind driven optimization.

Wind Driven Optimization Paradigm Using Lévy Flights Applied to Multiobjective Transformer Design

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In recent years, it was proposed a new optimization metaheuristic algorithm namely Wind Driven Optimization (WDO). WDO is a stochastic nature-inspired paradigm based on atmospheric motion. In this paper, a modified version of the WDO based on Lévy flights to tune the control parameters, named Lévy WDO (LWDO), is proposed and evaluated. Lévy flight or anomalous diffusion process is a random walk characterized by Markov chain in which the step-lengths have a probability distribution that is heavy-tailed. To validate the multiobjective optimization performance of the WDO and the proposed LWDO, a benchmark for optimizing of a safety isolating transformer is adopted. In this paper, the transformer design optimization is treated as a multiobjective problem, with the aim to minimize both the total mass (iron and copper materials) and losses taking into consideration design constraints. Simulation results testify that the LWDO is a promising approach for multiobjective optimization as it outperforms the classical WDO.

ID: 458 / PA3: 16

Track 07

Topics: Optimization and Design

Keywords: Particle swarm optimization, electric machines, finite element analysis, design optimization

Mass Ionized Particle Optimization Algorithm Applied to FEA based Optimal Design of Electric Machine

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An optimal design process of the electric machine is divided into optimization algorithm and characteristics analysis for calculation of objective function. The characteristic analysis of the electric machine is conducted primarily through Finite Element Analysis (FEA). Since FEA in electromagnetic analysis generally takes considerable computation time, it occupies most of convergence time in optimal design of electric machine. Thus, it is necessary to select appropriate optimization algorithm. In this paper, population based original optimization algorithm is suggested named Mass Ionized Particle Optimization (MIPO). To prove the validity of MIPO, well-known test function like Branin function is adopted to compare the proposed algorithm and another population based algorithm, like PSO. In addition, the algorithm has been applied to optimal design for the torque ripple reduction of Interior Permanent Magnet Synchronous Machine.

ID: 497 / PA3: 17

Track 08

Topics: Optimization and Design

Keywords: Finite element analysis, Fourier series, permanent magnet machines

Torque Ripple Prediction using Fourier Coefficients of Flux Linkage in PMSM Design

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To derive an estimate of torque ripple in permanent magnet synchronous motor (PMSM), analytic expression of torque is developed using the stator flux linkages. The flux linkage data are obtained from FEM analysis, and they are expressed as Fourier series after a dq transformation. Further, the torque equation is obtained using the Fourier coefficients and the first three harmonic components (6th, 12th, 18th) are used to make a torque ripple estimate. Through comparison studies, it is shown that the prediction matches well with the FEM results. The prediction may be used as a guide for reducing the torque ripple at the motor design stage.

ID: 524 / PA3: 18

Track 09

Topics: Optimization and Design, Material Modelling, Multi-physics and Coupled Problems

Keywords: Magnetostriction, transformers, multiscale modeling, iron-silicon alloys, finite element method.

Calculation of Magnetostriction Induced Deformations in Grain Oriented and Non-Oriented Silicon Iron Transformer Cores Thanks to an Imposed Magnetic Flux Method

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This work focuses on the development of an algorithm for the prediction of a transformer core deformation, using a magneto-mechanical approach. An imposed magnetic flux method coupled with finite elements is employed for the magnetic resolution. The constitutive law of the material uses a multi-scale model describing both magnetic and magnetostrictive anisotropies. Magnetostriction is introduced as an input free strain of a mechanical problem to get the deformation and displacement fields. The numerical process is applied to compare the deformations of a given magnetic circuit made of Grain Oriented and Non-Oriented FeSi.

ID: 542 / PA3: 19

Track 15

Topics: Novel Computational Methods for Machines and Devices

Keywords: AC Machines, Finite element analysis, Motor drives, Power systems transients

Initial state computation for steady-state analysis of induction motor fed by voltage inverter

Jérôme Cros, Maxim Bergeron, Philippe Viarouge

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The starting transients in time-stepping Finite Element Method (FEM) are an issue when we are interested in steady state values such as copper and magnetic losses. The time required to reach the steady-state currents is very long when the windings are supplied with a voltage source. However, if the initial state variables are known, there are no starting transient. This paper presents an efficient method to compute the initial conditions required for a FEM steady-state analysis. The method exploits a high order coupled circuit model where self and mutual inductances are identified by linear magnetostatic FEM. The simulations with this model are very fast and we can evaluate the steady-state currents of an induction machine, in a few seconds. The initial current and rotor position values are then applied to the FEM magnetodynamic simulation and it is possible to obtain the steady-state results with the simulation of only one period. The steady state computation method is validated by the study of a railway bogie made of two 350 HP induction traction motors supplied by the same GTO voltage inverter.

ID: 297 / PA3: 20

Track 14

Topics: Novel Computational Methods for Machines and Devices

Keywords: Electric motor, finite element method, mesh deformation, optimization.

A Mesh Deformation Algorithm and Its Application in Optimal Motor Design

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In this paper, a remesh-free morphing method is reported to speed up the modeling of electric motor (EM) in optimal design. Neither the mesh regeneration nor an increase in the number of unknowns is required for the proposed method. Refined meshes can be quickly derived using a coordinate mapping technique. The calculation time can therefore be greatly reduced when the geometric parameters are changed during the optimal design process. At the same time, the mesh quality is guaranteed to ensure the FEM calculation is accurate. Numerical results are reported to demonstrate the efficiency and effectiveness of the proposed method.

PA4: Optimization and design 1

Time: Monday, 29/Jun/2015: 1:45pm - 3:25pm · *Location:* Cafeteria

Session Chair: Abdul-Rahman A. Arkadan

Session Chair: Christian Magele

ID: 8 / PA4: 1

Track 01

Topics: Optimization and Design, Novel Computational Methods for Machines and Devices

Keywords: Electromagnetic fields, design optimization, superconducting devices, electromagnetic devices

Multi-Applicable Electromagnetic Field Design Method Based on Zero-One Programming

Tianqi Hong^{1,2}, Lei Huang¹, Haitao Yu¹, Minqiang Hu¹

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This paper proposes a method for developing the electromagnetic field under certain requirements. In this paper, the electromagnetic field design is considered as an optimization problem. Instead of solving this optimization problem directly, we rewrite the problem into zero-one programming form. By applying the proposed algorithm to solve the zero-one programming problem, the design requirements can be achieved and optimization time can be dramatically saved compared with using finite element method (FEM). Two practical applications are proposed to validate this novel method. All design results are compared with FEM calculation results.

ID: 41 / PA4: 2

Track 07

Topics: Optimization and Design

Keywords: Optimization, brushless DC motor design, krill herd algorithm, multiobjective optimization.

Multiobjective Krill Herd Algorithm for Electromagnetic Optimization

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Metaheuristics have recently become the forefront of the current research as a powerful way to deal with many electromagnetic optimization problems. Based on the simulation of the herding behavior of krill individuals, a krill herd (KH) algorithm was recently proposed to solve optimization problems. In order to extend the classical mono-objective KH algorithm approach, this paper proposes a new multiobjective KH (MKH) algorithm and a modified MKH approach using the beta distribution in the inertia weight tuning. Numerical results on a multiobjective constrained brushless direct current (DC) motor design problem show that the evaluated MKH algorithms present a promising performance.

ID: 66 / PA4: 3

Track 01

Topics: Optimization and Design

Keywords: design optimization, permanent magnet motors, rotating machines, sensitivity analysis

Topology Optimization of Electric Motor using Topological Derivative for Nonlinear Magnetostatics

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We aim at finding an optimal design for an interior permanent magnet electric motor by means of a sensitivity-based topology optimization method. The gradient-based ON/OFF method, introduced by M. Ohtake, Y. Okamoto and N. Takahashi in 2005, has been successfully applied to optimization problems of this form. We show that this method can be improved by considering the mathematical concept of topological derivatives. Topological derivatives for optimization problems constrained by linear partial differential equations (PDEs) are well-understood, whereas little is known about topological derivatives for nonlinear PDE constraints. We derive the topological derivative for an optimization problem constrained by the equation of nonlinear two-dimensional magnetostatics and show how this information can be used to obtain optimal designs.

ID: 144 / PA4: 4

Track 07

Topics: Optimization and Design, Novel Computational Methods for Machines and Devices

Keywords: Array thinning, nondominated sorting genetic algorithm II (NSGA-II), iterative fast Fourier transform (IFFT).

Large Planar Array Thinning with an Improved Multi-Objective Genetic Algorithm

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An improved multi-objective optimizer based on the nondominated sorting genetic algorithm II (NSGA-II) is presented for large planar array thinning in this work. The iterative fast Fourier transform (IFFT) technique with a judge factor is introduced into the optimizer to accelerate the convergence. In the early phase of the optimization algorithm, the global characteristics of GA occupy a major position and the powerful local characteristics of IFFT technique in the late phase. Thus, this proposed algorithm can not only effectively avoid being trapped into the local optimum, but also possess a fast convergence for large array thinning. A representative example shows the good performance of the proposed algorithm.

ID: 162 / PA4: 5

Track 13

Topics: Optimization and Design*Keywords:* design optimization, multi-component layout optimization method, permanent magnet actuator, parametric optimization, level set method**Multi-component Layout Optimization Method for the Design of a Permanent Magnet Actuator****Sunghoon Lim, Seungmin Jung, Seungjae Min**Hanyang University, Korea, Republic of (South Korea); sleeplim82@hanmail.net

Since the driving performance of the permanent magnet actuator (PMA) is dominated by the shape and position of the magnetic material, the development of an effective optimization design method has been an important issue in computational magnetics. Thus, some researchers have proposed a design method to optimize the length, position, and angle of the magnetic material, such as the permanent magnet (PM) and ferromagnetic material (FM), for enhanced performance of PMA by using a few geometrical parameters. However, the parametric design method is not suitable for the conceptual design stage because the optimal solutions strongly depend on the initial design. To overcome these limitations, the topology optimization method, which can guarantee a high degree-of-freedom in geometrical change, was applied to the magnetic design problem. This design method provided an innovative optimal design that can improve the PMA's performance dramatically, but at the cost of producing a highly complicated shape.

This paper presents a multi-component layout optimization method that incorporates a parametric and topology optimization method to determine the optimal shape of a PMA. The optimal position and size of the rectangular-type PM are obtained by the design sensitivities of size parameters. The level set based topology optimization method, which can guarantee a high degree-of-freedom in geometrical change, is employed to obtain the optimal distribution of the FM that can affect the path of the magnetic flux. The optimization problem is formulated to maximize the magnetic force of the PMA under the fixed volume fraction constraint of each material. The magnetic properties of the PM and FM, such as the magnetic relative reluctivity and the direction of the remanent magnetic flux, are calculated by the geometric parameters and the sign of the level set function. To confirm the effectiveness of the proposed method, a design example of a simple C-core actuator is provided.

ID: 176 / PA4: 6

Track 13

Topics: Optimization and Design*Keywords:* Design Optimization, finite element analysis, permanent magnet motors**Topology Optimization of IPM Motors: Minimization of Iron Losses****Shintaro Furui, Shunpei Sato, Takahiro Sato, Hajime Igarashi**Hokkaido University, Japan; sfurui@em-si.eng.hokudai.ac.jp

This paper presents topology optimization of IPM motors where their rotor shapes are determined so that the eddy current and hysteresis losses are minimized under the constraint that the average torque is greater than a given threshold. The topology optimization is performed using the on/off method based on the Normalized Gaussian network (NGnet). The rotor which has deep notches is found to be optimal because of its relatively small surface area where the iron losses concentrate.

ID: 194 / PA4: 7

Track 13

Topics: Optimization and Design*Keywords:* Electromagnetic coupling, optimization methods, gradient methods**Multidisciplinary optimization formulation to the optimization of multirate systems****Antoine Pierquin¹, Stéphane Brisset², Thomas Henneron¹**¹Université de Lille 1, L2EP, France; ²EC Lille, L2EP, France; ant.pierquin@gmail.com

Two approaches of multidisciplinary optimization are extended to a problem with a time-dependent model. The waveform relaxation method allows the modeling of a multirate system, then the multidisciplinary feasibility and the individual discipline feasibility strategies are used to define the optimization problem. With the second strategy, a way to obtain the jacobian of the operator associated to the waveform relaxation method is proposed.

ID: 392 / PA4: 8

Track 13

Topics: Optimization and Design*Keywords:* Circulating current loss, co-Kriging, optimal design, power transformer, transposition**Co-Kriging Assisted PSO Algorithm and Its Application to Optimal Transposition Design of Power Transformer Winding for the Reduction of Circulating Current Loss****Bin Xia, Gil-Gyun Jeong, Chang-seop Koh**Chungbuk National University, Korea, Republic of (South Korea); tiandixiabin@chungbuk.ac.kr

A numerically more efficient and accurate co-Kriging model is developed, and incorporated into particle swarm optimization to be applied to optimal design of electromagnetic devices. The sampling points in the co-Kriging consist of a few expensive data and many cheap data to save the computational efforts while increasing modeling accuracy. The proposed algorithm is validated through an analytic example, and applied to an optimal transposition design of a power transformer to minimize its circulating current loss.

ID: 432 / PA4: 9

Track 07

Topics: Optimization and Design*Keywords:* Particle Swarm Optimization, Mesh Adaptive Direct Search, Optimal Design, Permanent Magnet Synchronous Machine, Torque Ripple**An Novel Memetic Algorithm Using Modified Particle Swarm Optimization and Mesh Adaptive Direct Search for PMSM Design****Jin Hwan Lee¹, Jong-Wook Kim², Sang-Yong Jung¹**

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Optimization algorithm is used in many engineering fields and validated of its effectiveness. Therefore, it is frequently applying to designing electric machines. In order to increase performance and minimize design time, search efficiency of an optimization method is important. In this paper, explorative-particle swarm optimization (E-PSO) combined with mesh adaptive direct search (MADS) is newly proposed and applied to design of permanent magnet synchronous machine (PMSM). The memetic algorithm which is modified from PSO improves search time and the number of function call drastically. Unlike any existing method, newly used start point selection takes advantage of minimizing search time. By applying proposed algorithm to PMSM, we minimize torque ripple.

ID: 632 / PA4: 10

Track 11

Topics: Optimization and Design, Novel Computational Methods for Machines and Devices

Keywords: AC Machines, Finite element analysis, Frequency response, Uncertainty, Parameter estimation

Frequency-domain analysis of electrical machine dimensions and material property uncertainties by finite-element

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This paper presents a fast method to reduce the uncertainties on the machine geometrical dimensions and material properties. We use Finite-Element Analysis in the frequency domain to simulate StandStill Frequency Response (SSFR) tests of an existing electrical machine. We carry out parameter sensibility studies on the d-axis operational inductance using experimental data as the reference. The SSFR identification technique was chosen since its resolution is straightforward in 2D magneto harmonic and provides a detailed machine signature over a wide frequency range. The resolution is very fast and allows a more detailed meshing compared to time based simulations. The proposed method is validated using a 5.4 kVA turbo generator.

ID: 689 / PA4: 11

Track 07

Topics: Wave Propagation, Optimization and Design

Keywords: Genetic Algorithm, Evolution Strategy, Hybrid Algorithm, CPW-fed circularly polarized Antenna

A Study on Hybrid of Genetic Algorithm and Evolution Strategy for Antenna Design

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This paper proposes a hybrid algorithm based on Genetic Algorithm (GA) and Evolution Strategy (ES). The GA is not successful in searching an optimal solution in the view point of convergence speed and solution quality. The ES has the risk of being trapped in a local minimum. The hybrid algorithm is composed of GA and ES in order to make up for these defects of GA and ES. The procedure of searching an optimal solution in hybrid algorithm is as follows. Firstly, the vicinity of optimal solution is reached by using the GA. And then the ES is used to find an accurate optimal solution. In terms of the convergence rate, the proposed hybrid algorithm is compared with the GA using the optimal design of 2.45 GHz CPW-fed circularly polarized antenna. The results of the antenna optimized using GA and hybrid algorithm satisfy the objective value. The convergence rate graph shows that convergence rate of GA decreases and ES rapidly searches optimal solution in the vicinity of optimal solution after 380 iterations.

ID: 702 / PA4: 12

Two Pages Short Version

Topics: Optimization and Design

Keywords: Meta Modelling, Multi-objective Optimization, Sensorless Control

Kriging assisted multi-objective design of permanent magnet motor for position sensorless control

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This paper presents a novel formulation of electrical machine design for position sensorless control. Several quantitative characteristic values were defined for measuring the capacity of sensorless control. A multi-objective optimization is formulated for the design of a surface-mount permanent magnet motor in order to improve its sensorless capability without compromising the output torque. A surrogate-model based optimization algorithm is also proposed for reducing the number of evaluations of the computationally expensive finite-element analysis models.

ID: 384 / PA4: 13

Track 14

Topics: Optimization and Design

Keywords: Finite element mesh, optimization method, PSO, SQUID

A Robust Optimization Method using PSO with Multiple Finite Element Meshes for Minimizing Mesh Influence

So Noguchi, Naoya Terauchi, Hajime Igarashi

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An optimization method coupling an electromagnetic field simulation is widely employed for an electromagnetic device design. It is because an optimization method enables short development time and low material and development cost. A finite element method is often embedded with an optimization method. In finite element analysis, a simulation subject is subdivided into a mesh, and the accuracy of simulation is influenced by the mesh quality. Therefore, a solution obtained by the optimization method coupling the finite element method is also influenced by the mesh quality. In this paper, a modified PSO method is proposed to minimize the influence of the mesh quality. In the modified PSO method, multiple finite element meshes are employed, and the multiple optimal solutions are obtained. To decide a single final optimal solution from the multiple optima, a clustering technique is employed. To validate the proposed method, it is applied to an optimal design problem of a superconducting film magnetic shield for protecting a SQUID magnetometer and widening its effective area. By applying the proposed method, a realistic and expectable solution is obtained.

ID: 657 / PA4: 14

Track 08

Topics: Optimization and Design

Keywords: Finite Element Method, Response Surface Method, Power Frequency Withstand Voltage, Lightning Impulse Withstand Voltage

Simulation and Optimization of 252 kV High Voltage Busbar

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This study designed an improved 252 kV busbar structure through AutoCAD software. The simulation and optimization of electric field distributions in 252kV busbar have been investigated employing the Finite Element Method (FEM) and Response Surface Method (RSM) after the improvement of the 252 kV busbar structure. The electric field distribution of the optimal busbar structure was superior to that of the original structure. Under a relative gas pressure of 0.3 MPa, the optimal 252 kV busbar successfully withstood a power frequency voltage of 460 kV and a lightning impulse voltage of 1050 kV at 15 times the positive and negative polarity, respectively. Such improvement enhances the dielectric margin of the 252 kV busbar and reduces production cost by approximately 1000000 Yuan per year, and more meaningfully, the pollution of SF6 will also be greatly reduced.

ID: 412 / PA4: 15

Track 07

Topics: Optimization and Design

Keywords: Optimization methods, Electric machines, Design optimization, Heuristic algorithms, Computational efficiency

A Novel Multimodal Optimization Algorithm for the Design of Electromagnetic Machines

Chung-Hee Yoo^{1,2}, Dong-Kuk Lim¹, Hyun-Kyo Jung¹

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The optimal shape and parameter search during the design of an electromagnetic machine is a nonlinear, multivariable and multimodal optimization problem that incurs a great deal of computation time when calculating electromagnetic fields. To overcome these problems effectively, this paper proposes a new evolutionary multimodal optimization algorithm based on the Big Bang-Big Crunch method and aided by a surrogate model using the theory of compressed sensing. Its efficiency is demonstrated by assessing the optimization results for test functions. Moreover, to evaluate the feasibility of its application to an electromagnetic problem, a permanent magnet machine is designed using the proposed algorithm. The obtained results confirm that the proposed method is more effective and efficient than other existing approaches.

PA5: Mathematical modeling and formulations 2

Time: Monday, 29/Jun/2015: 1:45pm - 3:25pm · *Location:* Lounge

Session Chair: Gérard MEUNIER

Session Chair: Patrick Kuo-Peng

ID: 683 / PA5: 1

Track 09

Topics: Mathematical Modelling and Formulations

Keywords: Solenoid, Boundary value problem, Maxwell equation, Toroidal magnetic field

Analytical Calculation of the Magnetic Vector Potential of an Axisymmetric Solenoid in the Presence of Iron Parts

Hossein Vahid Alizadeh, Benoit Boulet

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This study presents an analytical solution for the magnetic vector potential of an axisymmetric solenoid in the presence of an iron shield and a ferromagnetic core. The analysis of the current carrying coil in the presence of ferromagnetic materials is treated as a boundary value problem. By assuming infinite permeability for the ferromagnetic materials, the effects of the iron parts are represented by the boundary conditions. The continuity of the magnetic vector potential and the magnetic field are taken into account by the interface conditions. The solution to this problem is obtained by partitioning the solution domain into distinct regions and solving the Maxwell's equation in each region by separation of variables. The final solution to the boundary value problem is constituted by applying the interface conditions on the solutions to the Maxwell's equations at the predefined regions.

ID: 664 / PA5: 2

Track 17

Topics: Mathematical Modelling and Formulations

Keywords: Preisach modeling, hysteresis modeling, uniaxial anisotropy, hysteron distributions

Modeling a distribution of uniaxial hysterons

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We recently published an article on a new model for a single uniaxial hysteron. We have now extended this model to collections of such hysterons. This extension is designed to be expandable so that it can describe such phenomena as accommodation, aftereffect and magnetostriction. The current model assumes that all the hysterons are aligned perfectly, but have different switching characteristics. We discuss how this model can be incorporated for an assembly of such hysterons.

ID: 633 / PA5: 3

Track 10

Topics: Mathematical Modelling and Formulations

Keywords: Anisotropic constitutive power law, Discontinuous Galerkin Method, Heterogeneous superconducting media, Maxwell equations

3D Modeling of heterogeneous and anisotropic superconducting media

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In this paper, we investigate the 3-D computation of the current distribution in an heterogeneous superconducting media with a discontinuous anisotropic $E - J$ constitutive power law. The resulting 3-D vectorial non-linear diffusion problem satisfied by the electric field is solved in each region of the media with a symmetric interior penalty discontinuous Galerkin method combined with a 3D semi-implicit scheme recently proposed for the 3-D modeling of homogeneous bulk superconductors. A numerical example on a media consisting of two different anisotropic superconducting regions inside a conductive matrix is computed. While the critical electric field E_c is uniform, both critical current density J_c and power law exponent n are uniform in each region but discontinuous in the media. It can be seen that the numerical method proposed is stable and convergent.

ID: 586 / PA5: 4

Track 20

Topics: Mathematical Modelling and Formulations, Numerical Techniques, Multi-physics and Coupled Problems, Novel Computational Methods for Machines and Devices

Keywords: Magnetic fields, permeability, numerical analysis, eddy currents, radial basis function

Using Definition of Permeability Tactfully to Solve Multi-medium Eddy Current Problems Involving Movement by RBF

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This paper presents a novel approach, radial basis function (RBF) collocation method combined with principle of electromagnetic field superposition based on definition of permeability to solve multi-medium problems with moving conductor. Using the definition of permeability, the magnetic field can be divided into two kinds of fields generated respectively by the excitation current and magnetizing current in multi-medium problems. With the movement of medium, the magnetizing current is also moving. Hence, moving coordinate systems in which the field generated by magnetizing current is calculated can be used to avoid the reset of the nodes with RBF collocation method. The field of eddy current can also be computed in the same way, so the proposed method is useful to solve multi-medium eddy current problems involving movement. Two numerical examples are computed to verify the method.

ID: 569 / PA5: 5

Track 11

Topics: Numerical Techniques

Keywords: Impedance Boundary Condition, Boundary Element Method, Hybrid Techniques, Induction Heating

Finite Formulation of Impedance Boundary Condition**Vincenzo Cirimele¹, Fabio Freschi^{1,2}, Luca Giaccone¹, Maurizio Repetto^{1,2}**¹Politecnico di Torino, Italy; ²The University of Queensland, Australia; maurizio.repetto@polito.it

In several electromagnetic applications field quantities are confined in layers which are thin with respect to other geometrical dimensions, like in skin effect. The numerical solution of these phenomena has led to the development of special formulations. Among these, the Impedance Boundary Conditions has been extensively developed in the past decades, often coupling it to other techniques for the analysis of volumes like finite elements or boundary elements method. In this paper a finite formulation of the Impedance Boundary Condition is presented and its application to the analysis of induction heating problems is proposed. The novelty of the paper lies in the definition of the operative quantities present in the formulation and in its development toward an iterative technique which takes into account magnetic nonlinearity.

ID: 555 / PA5: 6

Track 04

Topics: Mathematical Modelling and Formulations

Keywords: Eddy current, space-time finite element, speed electromotive force

A Preliminary Study of Space-time Finite Element Eddy-current Analysis**Junichi Niimi, Takeshi Mifune, Tetsuji Matsuo**Graduate school of Engineering, Kyoto University, Japan; niimi.junichi.57e@st.kyoto-u.ac.jp

A space-time finite element method is developed for the eddy-current analysis that can handle temporally-variant spatial finite elements arising in the analysis of moving objects. The vector potentials allocated on space-time finite elements naturally expresses the speed electromotive force. Space-time parallelepiped and triangular prism finite elements are examined to represent the eddy-current field in space-time successfully.

ID: 546 / PA5: 7

Track 10

Topics: Numerical Techniques

Keywords: Conductor, Electric field, Finite element method, Surface charge

Numerical Analysis of Geometry Effect on Surface Charge and Electric Field in Current-Carrying Conductor**Kang Hyouk Lee¹, Suk Min Hong², Seung Geon Hong¹, Myung Ki Baek¹, Il Han Park¹**¹Sungkyunkwan University, Korea, Republic of (South Korea); ²MagnaChip Semiconductor, Korea, Republic of (South Korea); lkh1985@skku.edu

This paper presents a numerical method to calculate surface charge and electric field distributions in current-carrying conductor. The proposed method is based on the finite element method, so that it can be applied to conductors of arbitrary geometry. In this analysis, two Laplace equations are sequentially solved because the material properties of the conductor and the region outside the conductor are incompatible in an equation. Accurate calculation of surface charge and electric field distributions using the proposed method can widen understanding of physical phenomenon due to the geometry effect. To show usefulness of this method, numerical models with different shaped conductor are analyzed.

ID: 514 / PA5: 8

Track 16

Topics: Mathematical Modelling and Formulations, Material Modelling

Keywords: material modeling, magneto-electric effect, moving medium

Emulation of stationary moving medium by magneto-electric material in the finite element method**Szabolcs Gyimóthy**Budapest University of Technology and Economics, Hungary; gyimothy@evt.bme.hu

The numerical simulation of electromagnetic phenomena involving moving bodies is always challenging when the effect of motion becomes significant. We propose a novel method by which the first order "motional term" of the partial differential equation (PDE) can be incorporated into PDE coefficients normally describing material characteristics. The method is general in the sense that various types of moving media (e.g. metal, dielectric) can be treated in a similar way. The most straightforwardly it can be utilized in the analysis of models with stationary geometry, and it may have some advantages over other approaches in this field. The method is demonstrated through examples.

ID: 493 / PA5: 9

Track 20

Topics: Mathematical Modelling and Formulations, Numerical Techniques

Keywords: finite element method, integral equation, multi-solver, resonant wireless power transfer

Finite Element – Integral Equation Full-Wave Multi-Solver for Efficient Modeling of Resonant Wireless Power Transfer**Zsolt Badics¹, Sandor Bilicz², Szabolcs Gyimóthy², Jozsef Pavo²**¹Tensor Research LLC, United States of America; ²Budapest University of Technology and Economics, Hungary; ZBadics@TensorResearch.com

In resonant WPT (wireless power transfer) systems several components with different material properties are often in the vicinity of the resonant coils. In order to efficiently model such systems a novel full-wave multi-solver is developed where the TVFEM (tangentially continuous vector finite element method) is coupled with a MoM (method of moments) solver based on an integro-differential system specifically designed to model the near singular behavior of the thin coil wires. A simplified sequential version of the multi-solver is also

introduced where the electromagnetic field of the coils in homogeneous material background is considered as an incident field and thus computed by the MoM technique as a first step. The incident field then plays the role of the source for the TVFEM utilizing the scattered field formulation, thereby calculating the scattered part of the field as a second step. Numerical results are presented to illustrate the behavior of the multi-solver approach.

ID: 398 / PA5: 10

Track 20

Topics: Mathematical Modelling and Formulations, Numerical Techniques

Keywords: balancing domain decomposition method, finite element analysis, magnetostatics, multigrid methods

A Balancing Domain Decomposition Method for Magnetostatic Problems with a Multigrid Strategy

Daisuke TAGAMI

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A balancing domain decomposition (BDD) method is considered as a preconditioner of the iterative domain decomposition method (DDM) for magnetostatic problems. The BDD method enables us to keep convergence properties of the iterative DDM even if the number of subdomains increases. However, in case of magnetostatic problems, the dimension of the coarse problem required in the BDD procedure depends on the number of nodal points of the discretization based on the finite element method. This fact causes that computational costs increase as computational models become larger. Therefore, to reduce the computational costs, a kind of multigrid strategy is introduced into the BDD procedure.

ID: 383 / PA5: 11

Track 05

Topics: Mathematical Modelling and Formulations, Multi-physics and Coupled Problems

Keywords: Magnetic Forces, Finite Element Analysis, Benchmark

Finite Element Implementation and Experimental Validation of 2D/3D Magnetic Force formulae

Walid Boughanmi¹, François Henrotte², Abdelkader Benamou¹, Yvonnick Le Menach¹

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The purpose of this paper is to provide practical guidelines for the Finite Element implementation of magnetic force formulae in 2D/3D and considering various linear or nonlinear materials. An experimental validation setup is also described in details, for which accurate measurements have been carried out, so that it can serve as a benchmark. A number of issues regarding accuracy and convergence are also dealt with.

ID: 380 / PA5: 12

Track 04

Topics: Static and Quasi-Static Fields, Mathematical Modelling and Formulations

Keywords: boundary element method, coupled numerical methods, natural element method

Higher Order Natural Element Method – Boundary Element Method Coupling

Douglas Martins Araujo^{1,2,3}, Diego Pereira Botelho^{1,2}, Yves Marechal^{1,2}, Jean-Louis Coulomb^{1,2}, Brahim Ramdane^{1,2}, Olivier Chadebec^{1,2}

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The advantage of a hybrid approach coupling natural element method (NEM) and boundary element method (BEM) is the conjunction of the inherent NEM accuracy and the BEM ability in modeling linear and deformable domains without any mesh. In a previous work, the coupling between standard NEM (1st order consistency) and a 0th order BEM was introduced. In the present work the performance of this coupling is tested for both methods in higher order versions. Results are presented in terms of convergence analysis and compared to a classic FEM-BEM coupling in terms of accuracy. The approach developed yields more accurate results with better convergence behavior, proving to be a good alternative in terms of accuracy for the simulation of unbounded problems

ID: 204 / PA5: 13

Track 19

Topics: Mathematical Modelling and Formulations, Numerical Techniques

Keywords: Capacitive effect, displacement current, edge-element, finite element method, nonlinear material, three-dimensional.

Application of Edge-Elements to 3-D Electromagnetic Field Analysis Accounting for Both Inductive and Capacitive Effects

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Traditional low-frequency eddy-current solvers do not include displacement current effect while high-frequency solvers do not take into account the nonlinearity of material properties. A novel solver for electromagnetic field analysis that addresses both inductive and capacitive effects is thus highly valuable. A stable time-domain magnetic vector potential (MVP) formulation, which includes both inductive and capacitive effects, is proposed and numerical examples are solved using the proposed formulation. The proposed MVP formulation is very promising in further engineering applications.

ID: 21 / PA5: 14

Track 14

Topics: Static and Quasi-Static Fields, Mathematical Modelling and Formulations

Keywords: Cell Method, Finite Integration Technique, Boundary Element, Integral Equation, Magnetostatics

Indirect Coupling of the Cell Method and BEM for Solving Three--Dimensional Unbounded Magnetostatic Problems

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A novel hybrid approach for solving magnetostatic problems with an unbounded air domain is presented. The basic idea is to use augmented dual grids for interfacing the Cell Method and BEM by indirect coupling, introducing equivalent surface field sources. The field problem in finite domains is discretized by the Cell Method in terms of integral variables, i.e. line integrals of the magnetic vector potential. Boundary integral conditions, formulated with the reduced magnetic scalar potential, are applied to avoid the air region meshing. A mixed final symmetric algebraic system, which can be solved by fast iterative solvers like MINRES or SYMMLQ, is finally obtained. The magnetic field in the air region is then easily reconstructed from equivalent sources. Numerical tests show that the hybrid method is accurate even by using a collocation approach for discretizing boundary integral conditions.

ID: 38 / PA5: 15

Track 04

Topics: Static and Quasi-Static Fields, Mathematical Modelling and Formulations, Numerical Techniques

Keywords: Magnetostatics, Finite Integration Technique, Uncertainty

Non-Intrusive and Intrusive Stochastic Finite Integration Technique for Magnetostatics

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Both non-intrusive and intrusive stochastic approaches based on Polynomial Chaos Expansions are presented for the Finite Integration Technique over generic polyhedral grids for three-dimensional magnetostatic linear problems. Such algorithms outperform Monte Carlo methods, both in terms of accuracy and efficiency.

A novel efficient algorithm for the intrusive approach is also provided, by which the intrusive approach becomes much less computationally expensive than the non-intrusive approach.

Validation is carried out by solving a magnetic circuit where the reluctivity is uncertain.

ID: 206 / PA5: 16

Track 18

Topics: Mathematical Modelling and Formulations, Numerical Techniques

Keywords: Displacement current, edge-element, field-circuit coupling, finite element method, solid conductor, three-dimensional field.

An Electromagnetic Field and Electric Circuit Coupling Method for Solid Conductors in 3-D Finite Element Method

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Traditional low-frequency eddy-current solvers do not include stray capacitive effects while high-frequency solvers do not take into account of the internal regions of solid conductors and external circuit excitations. In this paper the application of the edge-element method to problems with both inductive and capacitive effects for solid conductors under external circuit excitations using the formulation with a magnetic vector potential and an electric scalar potential is presented. A novel field-circuit coupling method is presented, which has the advantage of being convenient in algorithm implementation. A numerical example is given to showcase the proposed formulation and the developed edge-element program.

ID: 134 / PA5: 17

Track 20

Topics: Static and Quasi-Static Fields, Mathematical Modelling and Formulations, Numerical Techniques

Keywords: Boundary element method (BEM), eddy currents, stream function, thin shields, non-manifold geometry

A boundary element method for computing eddy currents in non-manifold thin conductors

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We present a novel technique to solve eddy current problems in non-manifold thin conductors by a Boundary Element Method (BEM) based on a stream function.

PA6: Multi-scale modeling and homogenization; Electromagnetic sensors and metrology

Time: Monday, 29/Jun/2015: 1:45pm - 3:25pm · Location: Lounge

Session Chair: Andrzej Demenko

Session Chair: Stephan Russenschuck

ID: 14 / PA6: 1

Track 08

Topics: Electromagnetic Sensors, Sensing and Metrology

Keywords: Electromagnetic analysis, Inspection, Nondestructive testing, Magnetic properties

Evaluation of non-destructive inspection for carburization depth of both surface and opposite side on steel tube using 3D nonlinear FEM

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In the steel tube of a heating furnace in an oil-refining plant, its both surface and opposite side is carburized. If these carburization depths are increased, the steel tube will be exploded suddenly and a big accident may occur. Therefore, the inspection of these carburization depths is important. The conductivity of the layer with carburization is larger than the layer without carburization in the steel, and its permeability is smaller than the layer without carburization. Therefore, the estimation of both carburization depths is possible by using the differences of these electromagnetic properties.

In this paper, the new technique of measuring the both depths by using two kinds of alternating magnetic field is proposed. The both depths are obtained by evaluating the flux density in layers with and without carburization steel tube using the 3-D nonlinear FEM. It is shown that the inspection of both depths is possible by using the differential electromagnetic characteristics.

ID: 20 / PA6: 2

Track 09

Topics: Electromagnetic Sensors, Sensing and Metrology

Keywords: eddy current testing, spiral search coil, (1+1) evolution strategy, 3-D magnetic FEM

Evaluation of magnetic field inside spiral search coil using evolution strategy in mutual induction eddy current testing

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The mutual induction type eddy current testing using a spiral type search coil is one of the eddy current testing (ECT). In this type ECT probe, since the thickness of a spiral search coil is very thin, the distance (lift-off : Lo) between the ECT probe and the specimen is able to set small. Therefore, the high detection sensitivity is obtained. However, since the wire is coiled in the shape of spiral, the evaluation of the flux density inside the spiral search coil is made difficult by experiment. Moreover, the phenomenon elucidation of inspection using this ECT probe is not carried out.

In this paper, the inspection characteristic of a surface defect on an aluminum plate using this probe was investigated by 3-D alternating electromagnetic finite element method (FEM). Moreover, the evaluation in consideration of the characteristic of the spiral search coil in this ECT probe is also investigated by (1+1) evolution strategy. It is shown that high detection sensitivity is obtained using the spiral search coil.

ID: 56 / PA6: 3

Track 18

Topics: Static and Quasi-Static Fields, Optimization and Design, Numerical Techniques, Electromagnetic Sensors, Sensing and Metrology

Keywords: Eddy currents, Finite element analysis, Nondestructive testing, Uncertainty

Uncertainty Analysis in Lorentz Force Eddy Current Testing

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The present paper addresses the analysis of uncertainties in the framework of the nondestructive evaluation technique Lorentz force eddy current testing. A generalized polynomial chaos expansion is used in order to quantify the impact of multiple unknown input parameters. In this context, the velocity and the conductivity of the specimen as well as the magnetic remanence and the lift-off distance of the permanent magnet are modelled as uniform distributed random variables. A comparison to experimental results show good agreement to numerical predictions. A sensitivity analysis by means of a sobol decomposition revealed that the magnetic remanence and the lift-off distance contribute to more than 80% to the total variance of the resulting Lorentz force profile.

ID: 182 / PA6: 4

Track 17

Topics: Electromagnetic Sensors, Sensing and Metrology

Keywords: Eddy currents, Magnetic sensors

Accuracy Improvement of a Magnetic Sensor Signal of an Excavator Using 3-D FEM

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High-class excavators have magnetic position sensors on a bucket, arm, and boom in order to inform the position of the bucket to the operator. The sensor signal is influenced by the eddy current. Therefore, the relationship between the stroke speed and sensor signal must be informed in order to compensate the bucket position. This paper describes an accuracy improvement of the magnetic sensor signal of the excavator using 3-D FEM and a compensation method of the bucket position. Finally, the compensation method is verified by carrying out measurements through a bench test.

ID: 216 / PA6: 5**Track 10***Topics:* Static and Quasi-Static Fields, Numerical Techniques*Keywords:* Finite element analysis, Electrostatics, Magnetostatics, Magnetic anisotropy**Interface Homogenization Technique for Electromagnetic Finite Element Analysis Including Anisotropic Media****Takeshi Mifune**Kyoto University, Japan; mifune.takeshi.3v@kyoto-u.ac.jp

In some electromagnetic finite-element applications, using a mesh that is not fitted to the geometry of the analyzed objects can provide substantial advantages over a standard fitted mesh in that, for example, moving objects are efficiently handled with no mesh reconstruction. Unfortunately, an unfitted mesh around the interfaces generally leads to a large numerical error. In this study, we present an enhanced version of the interface homogenization technique, which is a recently proposed technique that improves the accuracy of the unfitted finite element analysis, to enable anisotropic media to be handled.

ID: 225 / PA6: 6**Track 16***Topics:* Static and Quasi-Static Fields, Numerical Techniques*Keywords:* Electromagnetic analysis, finite element methods, multigrid method**Application of Homogenization Technique to Geometric Multigrid Method for Electromagnetic Finite Element Analysis****Tsubasa Kimura, Takeshi Mifune, Tetsuji Matsuo**Kyoto University, Japan; kimura@fem.kuee.kyoto-u.ac.jp

The geometric multigrid method is an efficient solver for large sparse matrix equations arising in finite element analyses and is widely used to solve various electromagnetic problems. However, this method has difficulty in generating hierarchical computational grids for complicated geometries. Although using a structured mesh can mitigate this difficulty, it becomes an inconvenience for finite element analysis in practical cases. This paper proposes a homogenization technique for the geometric multigrid method, which resolves the difficulty in representing various geometries by simple grids. A sample analysis of the electrostatic field suggests the promising performance of the proposed method.

ID: 240 / PA6: 7**Track 12***Topics:* Static and Quasi-Static Fields, Numerical Techniques, Material Modelling, Multi-scale modelling and homogenization*Keywords:* Multiscale modeling, Waveform relaxation method, FE method, Eddy currents, Magnetoquasistatic problems.**Waveform Relaxation for the Computational Homogenization of Multiscale Magnetoquasistatic Problems****Innocent Niyonzima^{1,2}, Christophe Geuzaine³, Sebastian Schöps^{1,2}**

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This paper deals with the application of the waveform relaxation method for the homogenization of multiscale magnetoquasistatic problems. In the proposed approach, the macroscale problem and the mesoscale problems are solved separately using the finite element method on the entire time interval for each waveform relaxation iteration. The exchange of information between both problems is carried out using the heterogeneous multiscale method.

ID: 332 / PA6: 8**Track 05***Topics:* Electromagnetic Sensors, Sensing and Metrology*Keywords:* magnetic flux leakage, nondestructive testing, pipeline, depth estimation, defect**A Study on the Estimation of Defect Depth in MFL type NDT System****Hui Min Kim, Dong Wook Jeong, Sang Hyeon Im, Jeong Hoon Park, Jin Seok Lee, Gwan Soo Park**Pusan National University, Korea, Republic of (South Korea); hmkim@pusan.ac.kr

MFL(Magnetic Flux Leakage) type NDT(Nondestructive testing) has been applied for the highly efficient inspection of defects in ferromagnetic materials such as underground gas pipelines. In the system, the magnetic field is applied to magnetize a steel pipe so that it can induce the leakage signal in the vicinity of defects on the pipe. In terms of the maintenance of underground pipelines, because the measured signal contains the size and shape information of defect, it is necessary to make the decomposing or estimating method for the sizing and shaping of defects by using sensor signals. Especially, the depth estimation is the most important procedure for management of safety accident. However, the previous method of estimating depth has high error rate compared to the actual measurement value of defects. So, this paper focused on the enhanced algorithm for the depth sizing in various kinds of defects by using measured signals. Estimated results in this paper agreed well with actual measurement values.

ID: 388 / PA6: 9**Track 15***Topics:* Electromagnetic Sensors, Sensing and Metrology*Keywords:* eddy currents, frequency response, non-destructive testing, numerical simulation**Non-destructive Evaluation of Conductive Materials by Eddy Current Swept Frequency Technique****Andrea Stubendekova¹, Pavel Karban², Ladislav Janousek¹, Frantisek Mach²**

¹University of Zilina, Faculty of Electrical Engineering, Slovak Republic; ²University of West Bohemia, Faculty of Electrical Engineering, Czech Republic; andrea.stubendekova@fel.uniza.sk

Novel approach in continuous non-destructive evaluation of conductive materials is concerned in the paper. Swept frequency excitation is employed to drive eddy currents in a conductive object. A conductive plate made of austenitic steel with artificial electro discharge

machined notches is inspected in this study. The notches differ in depth. Various eddy current probes are employed for the inspection in order to evaluate their resolution characteristics concerning the depth of a detected defect. An eddy current probe is fixed at a certain position during the inspection, while the frequency of harmonic exciting current is changed in a wide range. Induced voltage in a pick-up coil of a probe is sensed. Frequency characteristics of the induced voltage for different notches are evaluated in order to assess the resolution capabilities. Numerical model of inspection is created in LTspice and COMSOL Multiphysics softwares and it connects a model of high frequency coil with a measurement chain. Experimental measurements are carried out as well and the results are compared and discussed. It is shown that novel eddy current swept frequency technique can be employed in continuous non-destructive monitoring of conductive structures.

ID: 507 / PA6: 10

Track 10

Topics: Multi-physics and Coupled Problems, Novel Computational Methods for Machines and Devices

Keywords: Laminated CFRP, NDT, Induction Thermography, Thin Region, Anisotropic material, Degenerated Whitney element

Application of multi-layer degenerated Whitney elements in modeling of NDT induction thermography

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In this paper, multi-layer degenerated Whitney elements are used to modeling Carbon Fiber Reinforced Polymer (CFRP) composites in Non Destructive Testing (NDT) induction thermography technique. These elements avoid meshing the thin regions of composite and take into account the anisotropic multi-layer characteristic of the materials and also the flaws inside their volume. The eddy current problem is solved using $A - \phi$ formulation. The accuracy of this method is shown by comparison with classical hexahedral elements.

ID: 515 / PA6: 11

Track 12

Topics: Mathematical Modelling and Formulations

Keywords: Fall of Potential Method, Grounding System, Grounding Grid Resistance, Urban Substations

New Methodology to Measure the Grounding Grid Resistance of Substations Applying Short Distance Among Electrodes

Marcos Telló¹, Guilherme A. D. Dias², Daniel S. Gazzana², Roberto J. Cabral², Roberto C Leborgne², Arturo S. Bretas³

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This paper presents the development of an analytical formulation which estimates the reduced position of the current electrode and potential probe used for measuring the grounding grid resistance of the substations located in urban areas. The methodology was validated using data from measurements made in an experimental grounding grid and subsequent field test measurements of large substation grounding systems. The results show the accuracy of the proposed novel method applied when the testing area does not permit large separations among the electrodes involved in the measurements

ID: 523 / PA6: 12

Track 13

Topics: Material Modelling, Multi-physics and Coupled Problems, Multi-scale modelling and homogenization

Keywords: Eddy currents, Materials science and technology, Heat treatment, Numerical simulation

Numerical Simulation of Solid-Solid Phase Transformations During Induction Hardening Process

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Since many years, induction hardening has been successfully applied for the heat treatment of components, mainly in the aeronauti-cal and automotive sectors, because of its peculiar advantages like high quality and repeatability of process and its easy automation. A multi-scale multiphysical finite element (FE) analysis is presented in this paper for the prediction of microstructural evolution during induction hardening processes. An ad hoc code has been developed in order to calculate the metallurgical phase changes that occur during heating and cooling steps. This routine has been coupled with commercial FEM codes able to solve the coupled electromagnetic and thermal problem that typically describes the induction heating processes. During the heating, the magnetic field generated by the coil induces currents in the workpiece and as consequence the heating of conductive material by Joule effect. In induction hardening of steels, an external layer of the piece is heated up to the austenitization temperature, then it is cooled down to obtain a layer of marten-site. In thermo-metallurgical model, material properties depend on the temperature distribution but also on the microstructure since the material is a mixture of different phases. From the solution of the coupled steady-state, at a given frequency, electromagnetic and transient thermal problem, temperature distribution as well as heating and cooling rates are used for the evaluation of the existing met-allurgical phases at every time step. The effect of latent heat of solid-solid phase transformations has been also considered.

ID: 526 / PA6: 13

Track 06

Topics: Static and Quasi-Static Fields, Electromagnetic Sensors, Sensing and Metrology

Keywords: Analytical model, Inductance measurement, Magnetic sensors, Numerical simulation

Analytical Model and Finite-Element Model of an Inductive Displacement Sensor With a Highly Conductive Marker

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The displacement of a metal sphere causes a change of inductance in a measurement coil. This effect is adequately represented by a finite-element model as well as by a semi-analytical formula, both validated by measurements. The displacement sensor is built in an artificial lens for cataract patients.

ID: 549 / PA6: 14

Track 16

Topics: Novel Computational Methods for Machines and Devices

Keywords: Non Instrusive methods, Least Angle Regression, Uncertainty Quantification, Magnetolectric Effect, Finite Element Formulation

Non instrusive uncertainty quantification method for models with a high number of parameters - Application to a magnetolectric sensor

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To face the "curse of dimensionality" met in uncertainty quantification when a model has a high number of parameters, method based on sparse approximation, like the Least Angle Regression (LAR) method, should be used. In this communication, we propose to apply methods derived from the LAR method to quantify the impact of uncertainty on a magnetolectric sensor performances. The sensor response is represented by a 2D finite element model with 10 parameters. A global sensitivity analysis is carried out in order to determine the most influential parameters.

ID: 614 / PA6: 15

Track 02

Topics: Multi-scale modelling and homogenization

Keywords: Excess loss, domain wall, laminated core

Iron Loss Modelling of Laminated Core Considering the Excess Loss Due to Domain Wall Bowing

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Iron loss prediction of high-frequency magnetic components is essential for industrial application. Numerical iron loss analysis of laminated core usually involves a tradeoff between accuracy and efficiency. To improve the accuracy, this paper applies a numerical modelling method considering excess loss due to domain wall bowing. In order to reduce computational cost, 3D core and 1D lamination combined analysis is implemented in the method. For the flux parallel to the lamination is dominant, the excess loss due to domain wall bowing is considered only in the 1D analysis. The laminated structure is meshed in the 1D nonlinear eddy current analysis and an initial flux representing domain wall bowing is introduced. This numerical model provides the foundation of magnetic loss estimation for design and optimization of magnetic components, especially for high-frequency application.

ID: 617 / PA6: 16

Track 15

Topics: Static and Quasi-Static Fields, Multi-scale modelling and homogenization

Keywords: eddy currents, finite-element methods (FEMs), homogenization, lamination stack

Time-domain finite-element homogenisation of laminated iron cores with net circulating currents

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This paper deals with the time-domain homogenization of laminated cores in 2D or 3D finite element (FE) models of electromagnetic devices, in particular allowing for net circulating current in the laminations (which may result from imperfect or damaged insulation). The homogenization is based on the decomposition of the variation of the induction in the lamination thickness by means of a orthogonal set of polynomial basis functions, in conjunction with the magnetic vector potential (MVP) formulation.

The conventional even skin-effect basis functions are linked to net flux, whereas the odd ones are now considered as well so as to allow for net current. The approach is validated through a simple linear 2D test case, although the extension to 3D and nonlinear problems is straightforward.

ID: 646 / PA6: 17

Track 11

Topics: Static and Quasi-Static Fields, Numerical Techniques, Multi-scale modelling and homogenization

Keywords: Current vector potential, eddy currents, laminated media, multi-scale finite element methods, numerical simulation

Multi-Scale FEM Modeling of Eddy Currents with a Current Vector Potential *T* in Laminated Media

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The aim of the present work is to study multi-scale finite element methods of eddy currents in laminated media in two and three dimensions with a current vector potential. Material properties are assumed to be linear. Hence, approaches are developed for the frequency domain. The weak formulations are derived. Some numerical simulations are presented.

ID: 647 / PA6: 18

Track 11

Topics: Electromagnetic Sensors, Sensing and Metrology

Keywords: Eddy current testing, Finite element method, Multi output support vector machine, Particle Swarm Optimization, Genetic Algorithm

Crack Estimation using Adaptive Inversion Database With Multi Output Support Vector Machine for Eddy Current Testing

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Abstract- This paper considers the inverse problem of estimating the size of an unknown defect from the measurement of the impedance variations, By the novel combination of the multi output support vector machines (MO-SVM), and finite element modeling for eddy current flaw Characterization of a defect size in a conductive nonmagnetic plate. The finite element method (FEM) is used to create the database, In this context, the cylindrical sensor have been considered to validate a COMSOL-Multi physics 3D-resolution using a 3D electromagnetic formulation , A good agreement is obtained between the numerical results and the experimental ones. The database required to train the MO-SVM, Several method are used to find the parameters of MO-SVM. the Particle Swarm Optimization (PSO) ,Genetic Algorithm GA are proposed.

OA2: Mathematical modeling and formulations

Time: Monday, 29/Jun/2015: 3:50pm - 5:30pm · *Location:* Room #0100

Session Chair: Markus Clemens

Session Chair: Raffaele Martone

ID: 648 / OA2: 1

Track 04

Topics: Static and Quasi-Static Fields, Mathematical Modelling and Formulations, Numerical Techniques

Keywords: Finite element method, inductor, model refinement, subproblems

Progressive Current Source Models in Magnetic Vector Potential Finite Element Formulations

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Progressive refinements of the current sources in magnetic vector potential finite element formulations are done with a subproblem method. The sources are first considered via magnetomotive force or Biot-Savart models up to their volume finite element models, from statics to dynamics. A novel way to define the source fields is proposed to lighten the computational efforts, via the conversion of the common volume sources to surface sources, with no need of any pre-resolution. Accuracy improvements are then efficiently obtained for local currents and fields, and global quantities, i.e. inductances, resistances, Joule losses and forces.

ID: 691 / OA2: 2

Two Pages Short Version

Topics: Mathematical Modelling and Formulations

Keywords: Magnetic fields, finite difference methods, finite element analysis, functional analysis, education.

On the Equivalence of Finite Difference and Finite Element Formulations in Magnetic Field Analysis

Andrzej Demenko¹, Jan Sykulski²

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Numerical 3D formulations using scalar and vector potentials are examined for magnetic fields, with emphasis on the finite difference (FDM) and finite element (FEM) methods using nodal and facet elements. It is shown that for hexahedral elements the FDM equations may be presented in a form similar to the FEM equations; to accomplish this the coefficients defining volume integrals in FEM need to be expressed in an approximate manner, while the nodes in FDM require supplementary association with middle points of edges, facets and volumes.

ID: 399 / OA2: 3

Track 10

Topics: Mathematical Modelling and Formulations, Numerical Techniques

Keywords: wireless power transfer, resonance, integral equation, method of images

Modelling of resonant wireless power transfer with integral formulations in heterogeneous media

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This paper deals with the electromagnetic simulation of magnetically coupled wireless power transfer. A recently proposed approach based on a full-wave integral formulation (applicable in homogeneous media only) is extended to the case of heterogeneous media to some extent. In this new integral formulation, a quasi-static approximation is introduced and the effect of a planar boundary between different dielectric half-spaces is treated by the method of images. The results show a performance as expected. The modelling of single coils and full WPT chains is possible.

ID: 279 / OA2: 4

Track 01

Topics: Static and Quasi-Static Fields, Mathematical Modelling and Formulations, Numerical Techniques

Keywords: volume integral formulation, equivalent circuit, facet and edge elements, vector potential, electromagnetism

A-T Volume Integral Formulation for Solving Electromagnetic Problems

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A new volume integral formulation for solving electromagnetic problems is proposed. Firstly, it is based on a facet interpolation for representing the electromagnetic problem through an equivalent circuit. Secondly, an A-T vector potentials formulation can be built thanks to the use of discrete geometric approach. The formulation is particularly well adapted for solving electromagnetic problems where air is preponderant.

ID: 489 / OA2: 5

Track 11

Topics: Static and Quasi-Static Fields, Mathematical Modelling and Formulations, Numerical Techniques

Keywords: Boundary Element Method, Adaptive Cross Approximation, Hierarchical matrix arithmetics, Eddy current problems

Sparsification of BEM matrices for large-scale eddy current problems

Piergiorgio Alotto¹, Paolo Bettini^{1,2}, Ruben Specogna³

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Integral formulations can be convenient for computing eddy currents in complicated electromagnetic systems. However, large-scale problems may quickly exceed the memory capacity even of very large machines since the matrices are fully populated. We aim at

illustrating how H-matrices with Adaptive Cross Approximation can provide an effective method to increase the size of the largest solvable problems by means of Boundary Element Methods based on stream functions with modest implementation effort.

OA3: Optimization and design

Time: Tuesday, 30/Jun/2015: 8:30am - 10:10am · *Location:* Room #0100

Session Chair: Oszkar Biro

Session Chair: Kay Hameyer

ID: 693 / OA3: 1

Two Pages Short Version

Topics: Optimization and Design

Keywords: Kriging, global optimisation, surrogate modelling, large datasets.

A Dual Kriging Approach with Improved Points Selection Algorithm for Memory Efficient Surrogate Optimisation in Electromagnetics

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The paper introduces a new approach to kriging surrogate model sampling points allocation. By introducing a second (dual) kriging during the model construction process the existing sampling points are reallocated to reduce overall memory requirements. Moreover, a new algorithm is suggested for selecting the position of the next sampling point by utilising a modified Expected Improvement criterion.

ID: 707 / OA3: 2

Two Pages Short Version

Topics: Optimization and Design

Keywords: Design Optimization, Multi-objective Optimization, Objective Reduction, Permanent Magnet Motors

Visualization and Analysis of Trade-offs in Many-Objective

Rodrigo Silva¹, Armin Salimi¹, Min Li¹, Alan Freitas³, Frederico Guimaraes², David Alister Lowther¹

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Presentation and visualization of trade-off solutions in many-objective optimization problems are difficult due to the large number of solutions and a hyper dimensional objective space. A recently proposed tool, know as aggregation tree (AT), can be used to analyze the degree of conflict between any two objectives in a many-objective problem. In this paper, we present a case study on the internal permanent magnet motor design with seven objectives. The results show that the AT is able to provide insight into the electrical machine design problem (in accordance with the common knowledge of physics) as well as guidance in the objective reduction.

ID: 47 / OA3: 3

Track 01

Topics: Optimization and Design

Keywords: Multiobjective optimization, genetic algorithm, Pareto optimality, magnetic field, finite-element analysis

Migration-corrected NSGA-II for improving multiobjective design optimization in electromagnetics

Paolo Di Barba¹, Fabrizio Dughiero², Michele Forzan², Elisabetta Sieni²

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The paper proposes a new strategy to improve the performance of a standard non-dominated sorting algorithm (NSGA) in approximating the Pareto-optimal solutions of a multi-objective problem by introducing new individuals in the population miming the effect of migrations. The design optimization of a power inductor, synthesizing a uniform magnetic field for magneto-fluid hyperthermia applications, is considered as a case study to assess the performance of the migration-modified NSGA algorithm.

ID: 401 / OA3: 4

Track 07

Topics: Nano-Electromagnetic Computation, Optimization and Design, Mathematical Modelling and Formulations, Numerical Techniques

Keywords: uncertainty quantification (UQ), robustness, topology, design optimization, nanoelectronics, power transistors.

Uncertainty Quantification for Robust Topology Optimization of Power Transistor Devices

Piotr Putek^{1,2}, Peter Meuris³, Roland Pulch², Jan ter Maten¹, Wim Schoenmaker³, Michael Günther¹

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In this paper we focus on incorporating a stochastic collocation method (SCM) into a topology optimization for a power semiconductor device with both material and geometrical uncertainties. Such geometrical and material variations, which result predominantly from lithography proximity and process imperfections, have a direct impact on its yield and performance. This results in a stochastic direct problem and in consequence, affects the formulation of an optimization problem. Specifically, we deal with the robust optimization of a power transistor in order to minimize the current density overshoots, since the change of the shape and topology of a device layout is the proven technique for the reduction of a hotspot area. The gradient of a cost functional is evaluated using the sensitivity equation and the adjoint variable method. In simulations, we apply the level set method with a distribution additionally modified by the topological derivative, for the representation of the interface. Finally, we show the results of the robust optimization for the power transistor device, which is an example of a relevant problem in nanoelectronics, and also used widely in the automotive industry.

ID: 452 / OA3: 5

Track 14

Topics: Optimization and Design

Keywords: Game theory, Optimal design, Inductive power transmission

Optimizing Transcutaneous Energy Transmitter using Game Theory

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Over the past recent years, several researches, seeking reliable Transcutaneous Energy Transmitters (TET), have used different type of optimization techniques with different objectives. Algorithms with multiple objectives and constraints resulted in different configurations in the Pareto front, making the decision of the final configuration harder. Moreover, the game theory has been gaining a lot of ground in the engineering design, mainly in decision-making in optimization problems. This research uses the advantage of the game theory together with genetic algorithm to find one final configuration of TET, which fulfills the specified constraints while optimizing different objective functions. It uses three players playing with six different variables which were assigned to each player in a strategic manner according to each player's target.

PB1: Static and quasi-static fields

Time: Tuesday, 30/Jun/2015: 10:30am - 12:15pm · *Location:* Cafeteria

Session Chair: Zsolt Badics

Session Chair: Osama Mohammed

ID: 7 / PB1: 1

Track 15

Topics: Static and Quasi-Static Fields

Keywords: Capacitance, Numerical simulation, Finite element analysis

An Accurate and Efficient Hybrid Method for the Calculation of the Equivalent Capacitance of an Arbitrary Shaped Coil

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In this paper we present a novel hybrid method to efficiently and accurately calculate the equivalent capacitance of an arbitrary shaped coil with circular cross section by using finite element method in 3D. To avoid the high mesh's effort and the computing time, a parallel-electrode capacitor as the basic cell is used to approximate the circular wires. According to the published analytical formula, an equivalent relative permittivity for the basic cell can be obtained to ensure the accuracy of the presented method. Since the formulas are derived under different physics insights, the optimal equivalent relative permittivity for different winding methods of the coil has been determined. Finally, the efficiency and the accuracy of the presented method are validated through the numerical results.

ID: 87 / PB1: 2

Track 04

Topics: Static and Quasi-Static Fields

Keywords: Finite Element Method, Eddy Current Problem, Domain Decomposition Method, Parallel Processing

Improvement of Convergence in Time-Harmonic Eddy Current Analysis by Hierarchical Domain Decomposition Method

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This paper deals with a large-scale 3D time-harmonic eddy current analysis using the Hierarchical Domain Decomposition Method (HDDM). To improve the convergence of the interface problem of the HDDM and to reduce the computation time, the HDDM is applied to the mixed formulation with the Lagrange multiplier. Because the conventional formulation is singular, it is expected that the characteristic of convergence of the interface problem is made bad. Therefore, in this paper, the mixed formulation of the A method with the Lagrange multiplier that is not singular is considered. As a result, the convergence of the interface problem is much improved, and the time-harmonic eddy current problem with 3.5 billion degrees of freedom is solved in about 9 hours.

ID: 93 / PB1: 3

Track 14

Topics: Static and Quasi-Static Fields, Mathematical Modelling and Formulations, Numerical Techniques

Keywords: Coils, Tolerance Analysis, High-Performance Computing.

A Derivatives Splitting Approach to Sensitivity Analysis of Magnets Design

Andrea Gaetano Chiariello, Alessandro Formisano, Francesco Ledda, Raffaele Martone, Francesco Pizzo

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The paper proposes a mixed analytical-numerical approach for an effective evaluation of the variation of the magnetic field generated by complex coils due to deformations respect to the nominal configuration. The coils are described with a set of synthetic parameters and the deformations can be described as variations of such parameters. The work is focused in the contest of sensitivity analysis but the methodology is quite general and can be easily extended in other fields.

ID: 103 / PB1: 4

Track 19

Topics: Static and Quasi-Static Fields, Numerical Techniques

Keywords: surface electric field, boundary element method, charge simulation method

A Boundary Element Method with Reduced-basis for Computing Electrical Field around Long Slim Conductors

Chijie Zhuang¹, Yong Zhang², Rong Zeng¹, Jinliang He¹

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Evaluation of surface electric fields, which is well described by Poisson equation, is of great importance in shielding failure evaluation in power system. This paper proposes a boundary element method with reduced surface density basis considering the fact the radius of the transmission line is much smaller than its length. Examples show the method is convergent and is more accurate than charge simulation method which is often used for the evaluation of surface electric field of long slim conductors.

ID: 138 / PB1: 5

Track 08

Topics: Static and Quasi-Static Fields, Numerical Techniques

Keywords: Corona, electromagnetic fields, transmission lines, time-domain analysis

A Time-domain Approach of Ion Flow Field around AC-DC hybrid Transmission Lines Based on Method of Characteristics

Bo Zhang, Jianghua Mo, Jinliang He, Chijie Zhuang

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When there is a HVAC power transmission line near a HVDC transmission line, the nonlinear ion flow field around the DC transmission line due to corona becomes more complex because the AC field affects the movement of the ions in the space. In this paper, a pair of first-order partial differential equations of the ion densities in time domain is derived. Then, a time-domain iterative approach based on the method of characteristics is presented to calculate the ion flow field around AC-DC hybrid transmission line. The advantage of the method is that almost all the variables can be obtained via analytic formulas and no large-scale system of equations needs to be solved. The calculated and the measured results are in good agreement.

ID: 208 / PB1: 6

Track 10

Topics: Static and Quasi-Static Fields

Keywords: Computational electromagnetics, integral equations, iterative algorithms, nonlinear magnetics

A New Method for the Computation of Nonlinear Magnetic Fields Due to Coils with Imposed Terminal Voltages

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Combining the treatment of the field nonlinearity by using the polarization fixed point technique with the application of the superposition allows a matrix formulation relating the magnetic induction to the coil fluxes and to the polarizations in the actual nonlinear media. Since the linear medium used in the adopted model has the same permeability at each iteration, the matrices involved are computed only once, before the start of the iterative procedure. The method is illustrated for two-dimensional fields. In the case of a periodic regime produced by coils with sinusoidal terminal voltages, each harmonic of the magnetic field can be analyzed independently. It is shown that the proposed method is convergent.

ID: 223 / PB1: 7

Track 12

Topics: Static and Quasi-Static Fields

Keywords: Integral equations, finite element method, transformer, magnetic field, magnetic flux, inductance

Application of the Integro-Differential Method for Precise Computation of the Magnetic Fields in Transformers

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Integro-differential method is applied for computation of the magnetic field in the short-circuited transformer. For achieving a high precision of the magnetic field intensity computation a finite element technique was used for the post-processing. The developed procedure ensured a high accuracy of the transformer inductances computation with the constant relative permeability of steel. The results of a numerical modeling were approved by comparing with experimental data.

ID: 235 / PB1: 8

Track 15

Topics: Static and Quasi-Static Fields, Mathematical Modelling and Formulations

Keywords: Coupling surface, Magneto-Quasi-Static limit

The Coupling Surface Method for the Solution of Magneto-Quasi-Static Problems

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In this paper we present a novel methodology for decoupling the solution of the Magneto-Quasi-Static (MQS) equations in subdomains, through a coupling surface and related equivalent currents. In particular, the solution outside the coupling surface is "condensed" with a suitable boundary condition. Different formulations can be used in each subdomain, hence allowing the most convenient approach to be used in each case. A simple test case is presented, showing the effectiveness of the method.

ID: 237 / PB1: 9

Track 10

Topics: Static and Quasi-Static Fields, Numerical Techniques

Keywords: Discrete Hodge operator, discrete geometric method, parasitic capacitance extraction, weighted triangulations

Dual Discrete Geometry Methods Based on Weighted Triangulations for Capacitance Extraction

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The accuracy and convergence of the discrete geometric method (DGM) in terms of scalar potential depend on the quality of spatial meshes. To improve performance of the DGM based on existing meshes, the concept of weighted triangulations is reviewed and introduced to optimally transport the circumcenter of element to a well-centered position which results in the modified formulas of Hodge operation. The dual DGMs based on weighted triangulations are reformulated over dual meshes. They both help to reduce the spatial discretization errors and accelerate electromagnetic field analysis to extract circuit parameters. The electrostatic field and capacitance extraction examples are studied. The numerical results demonstrate that the accuracy and stability of the DGM are improved.

ID: 246 / PB1: 10

Track 16

Topics: Static and Quasi-Static Fields

Keywords: Electric machines, finite element analysis, nonconforming mesh connection, parallel processing

Parallel Finite Element Analysis of Rotating Machines Based on Domain Decomposition Considering Nonconforming Mesh Connection

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This paper investigates effectiveness of a parallel finite element method (FEM) based on domain decomposition method taking account of nonconforming mesh connection between moving and fixed parts in magnetic field analyses of rotating machines. Numerical results of inter-bar current analyses in a cage induction motor that verify the effectiveness of the proposed method are presented.

ID: 256 / PB1: 11

Track 04

Topics: Static and Quasi-Static Fields, Numerical Techniques

Keywords: Arnoldi-Krylov projection, Centroidal Voronoi Tessellation, Model Order Reduction, Proper Generalized Decomposition, Proper Orthogonal Decomposition

Comparison of Model Order Reduction Methods like POD, CVT, Arnoldi-Krylov and PGD to solve quasistatic problems

Laurent Montier¹, Thomas Henneron¹, Benjamin Goursaud², Stéphane Clénet³

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In the domain of numerical computation, Model Order Reduction (MOR) methods are more and more applied in mechanics and have shown their efficiency in terms of computation time and memory requirements. In computational electromagnetics, research has started recently and the different methods available in the literature need to be compared in order to find the most efficient one. We propose to evaluate MOR approaches in order to solve linear magnetoquasistatic field problems. Therefore, the Proper Orthogonal Decomposition (POD), the Centroidal Voronoi Tessellation (CVT), the Proper Generalized Decomposition (PGD) and the Arnoldi-Krylov projection (AKP) are developed and compared.

ID: 277 / PB1: 12

Track 04

Topics: Static and Quasi-Static Fields, Numerical Techniques, Electromagnetic Sensors, Sensing and Metrology

Keywords: Balanced Proper Orthogonal Decomposition, Balanced Truncation, Model Order Reduction, Proper Orthogonal Decomposition

Balanced Proper Orthogonal Decomposition applied to magnetoquasistatic problems

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Model Order Reduction (MOR) methods are an active research field in the numerical analysis domain. They are applied to many different areas in physics, especially in mechanics because they allow to dramatically reduce the computational time. MOR is quite recent in electromagnetics and needs still to be investigated. The Proper Orthogonal Decomposition (POD) is the most famous one and has already shown very promising results. However, the POD approach minimizes the error in the L^2 sense on the whole domain and cannot be very accurate to calculate quantities of interest, like flux associated with a probe in region where the field is low. In this communication, we present the Balanced Proper Orthogonal Decomposition (BPOD) which extends the POD by taking account of probes in its model. The BPOD and POD approaches will be compared on a 3D linear magnetoquasistatic field problem.

ID: 283 / PB1: 13

Track 16

Topics: Static and Quasi-Static Fields

Keywords: edge elements, integral formulation, nonlinear magnetostatic, volume integral method

A Magnetic Vector Potential Volume Integral Formulation for Nonlinear Magnetostatic Problems

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This paper presents a novel volume integral formulation based on the interpolation of the magnetic vector potential on edge elements in order to deal with 3D nonlinear magnetostatic problems. The formulation ensures rigorously the solenoidality of magnetic induction. A strong point is that the convergence of the nonlinear resolution is easily reached after a few iterations without any relaxation. Computed results for the TEAM problem 13 and for an actuator demonstrate the efficiency and accuracy of this new formulation.

ID: 289 / PB1: 14

Track 20

Topics: Static and Quasi-Static Fields, Numerical Techniques

Keywords: multigrid, electroquasistatic, parallelism, GPUs

Transient Simulation of Nonlinear Electro-Quasistatic Field Problems Accelerated by Multiple GPUs

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This paper focuses on the acceleration of the numerical linear algebra for solving large nonlinear electroquasistatic (EQS) problems in time domain as they occur in high-voltage applications utilizing nonlinear electric field stress grading materials. An algebraic multigrid (AMG) scheme is executed on multiple GPUs as a preconditioner for the conjugate gradients method. The speed-up is further increased by exploiting the fact that repeated solutions of similar shaped systems must be obtained in the Newton-Raphson iterations of the implicit time-stepping scheme. A tailored update algorithm for the AMG preconditioner is proposed that clearly reduces the communication between GPUs and host.

ID: 331 / PB1: 15

Track 12

Topics: Static and Quasi-Static Fields

Keywords: Space charge, Numerical simulation, Charge carrier density

Charge Transport Simulation in Single-layer Oil-paper Insulation

Shuo Jin¹, Jiangjun Ruan¹, Zhiye Du¹, Guodong Huang², Lin Zhu³, [Weimin Guan¹](#), Lingyan Li¹, Zhifei Yang¹

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This paper proposed a simulation method for the charge transport in single-layer oil-paper insulation. The method of transient upstream finite element method (FEM) is derived in order to calculate the time variation of charge densities in medium. The numerical simulation model of charge transport in single-layer oil-paper insulation is established by applying transient upstream FEM to the transport equations of bipolar charges. With reasonable micro parameter, charge transport in an experimental object is simulated. The simulation results are consistent with the experimental data. This paper provides an exploratory research to the simulation of charge phenomenon in oil-paper, and has guiding significance to the design of oil-paper insulation.

ID: 359 / PB1: 16

Track 20

Topics: Static and Quasi-Static Fields, Numerical Techniques

Keywords: finite element method, magnetostatic problem, Waveform relaxation method

Time periodicity condition of magnetostatic problem coupling with electric circuit by Waveform Relaxation Method

[Guillaume Caron^{1,2}](#), Thomas Henneron¹, Francis Piriou¹, Jean-Claude Mipo²

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In numerical computation, the finite element (FE) method associated with external electric circuits is often used to evaluate electromagnetism devices with voltage sources. To study the solution of the steady state, the computation time can be prohibitive due to a large transient state compared with the time step used to discretize the time domain. In this communication, the Waveform Relaxation Method is developed to impose the steady state of the solution in the case of magnetostatic problem coupled with electric equation.

ID: 449 / PB1: 17

Track 16

Topics: Static and Quasi-Static Fields, Mathematical Modelling and Formulations, Numerical Techniques

Keywords: Eddy currents, nonlinear magnetics, finite element analysis, computational electromagnetics

Comparison of various methods for the finite element analysis of nonlinear 3D periodic eddy-current problems

[Rene Plasser¹](#), Yasuhito Takahashi², Gergely Koczka³, Oszkar Biro¹

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Two different techniques for the analysis of nonlinear, periodic eddy-current problems are compared using a 3-dimensional benchmark problem. The methods are the parallel time periodic-finite element method (TP-FEM) and the harmonic balance fixed-point technique (HBFP).

ID: 450 / PB1: 18

Track 11

Topics: Static and Quasi-Static Fields, Mathematical Modelling and Formulations, Numerical Techniques

Keywords: magneto-quasistatics, electro-quasistatics, finite elements (FEM), finite integration technique (FIT), frequency sweep

Fast frequency and material properties sweeps for quasi-static problems

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We introduce a novel technique that speeds up the computation of a frequency sweep or some parametric change of material properties around a nominal value in electro- or magneto-quasistatic problems. In place of using the usual practice of solving the complex systems arising at each frequency and at each material parameter value independently, our technique requires only one factorization of a real, symmetric and positive definite matrix. The solution at each frequency and each value of material parameter is then found with a few back-substitutions only. The obtained speed up is sensible and the implementation is straightforward, showing the usefulness of the proposed technique in practical applications.

ID: 462 / PB1: 19

Track 02

Topics: Static and Quasi-Static Fields, Numerical Techniques

Keywords: Electrostatics, Finite element methods, Integral equations, Floating potential conductors

FEM-DBCI Solution of Open-Boundary Electrostatic Problem in the Presence of Floating Potential Conductors

Salvatore Alfonzetti, Giovanni Aiello, Santi Agatino Rizzo, [Nunzio Salerno](#)

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This paper extends the hybrid FEM-DBCI method for the solution of open-boundary electrostatic problems to case in which some floating potential conductors are present in the system. The iterative solution scheme of the standard method is modified in order to deal with the unknown values of the potential of these conductors.

ID: 464 / PB1: 20

Track 02

Topics: Static and Quasi-Static Fields, Numerical Techniques

Keywords: Finite element method, boundary element method, integral equations, eddy currents

Eddy Current Computation by the FEM-SDBCI Method

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The hybrid FEM-SDBCI method is developed for the finite element computation of time-harmonic eddy current problems in open boundary domains. The method is similar to the well-known FEM-BEM, but it assumes a Dirichlet boundary condition on the truncation boundary instead of a Neumann one. Shorter solving times are obtained with respect to FEM-BEM.

ID: 466 / PB1: 21

Track 04

Topics: Static and Quasi-Static Fields, Mathematical Modelling and Formulations, Multi-physics and Coupled Problems

Keywords: Corona Discharge, Electrostatic Precipitators, Coupled Problems

Corona Discharge Simulation of Multiconductor Electrostatic Precipitators

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The paper considers corona discharge problems with multiple conductors, such as those appearing in some electrostatic precipitators. A common, precise condition is identified in which previous approaches proposed in literature fail. For dealing with these conditions, a novel formulation of the problem is proposed. Moreover, a Newton-Raphson scheme is defined for iteratively solving a non-standard Petrov-Galerkin Finite Element discretization of the problem. The presented approach is validated on a benchmark for which an analytical solution is known.

ID: 473 / PB1: 22

Track 15

Topics: Static and Quasi-Static Fields, Optimization and Design

Keywords: Accelerator Magnets, Numerical Analysis, Fourier Series, Electromagnetic Measurements

Generalized Harmonic Analysis of Computed and Measured Magnetic Fields

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In this paper we present a generalized approach for the harmonic analysis of the magnetic field in accelerator magnets. This analysis is based on the covariant components of the computed or measured magnetic flux density. The multipole coefficients obtained in this way can be used for magnet optimization and field reconstruction in the interior of circular and elliptical boundaries in the aperture of straight magnets.

ID: 663 / PB1: 23

Track 11

Topics: Static and Quasi-Static Fields

Keywords: Surface Discharge, Dielectric Liquid-Solid, Electrohydrodynamics, Finite Element Analysis, Multiphysics

Fully Coupled Finite Element Analysis for Surface Discharge on Solid Insulation in Dielectric Liquid with Experimental Validation

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In this paper, we examined the behavior of surface discharge initiation and propagation on the surface of insulating solid immersed in dielectric liquid. To build a generalized numerical technique for the surface discharge phenomena with the electrohydrodynamic (EHD) approach, we employed the Navier-Stoke's equation and introduced the temporal surface charge equation for charge accumulation on a dielectric liquid-solid interface as well as the ionization, dissociation, and recombination effects. To verify the numerical setup, the numerical result was compared to that of experiment obtained from the literature.

PB2: Material modeling 1

Time: Tuesday, 30/Jun/2015: 10:30am - 12:15pm · *Location:* Lounge

Session Chair: Johan Gyselinck

Session Chair: Tetsuji Matsuo

ID: 28 / PB2: 1

Track 12

Topics: Material Modelling, Multi-physics and Coupled Problems

Keywords: magnetic hysteresis, magnetoelasticity, magnetostriction, strain, stress

Modeling of Hysteresis Losses in Ferromagnetic Laminations under Mechanical Stress

Paavo Rasilo¹, Deepak Singh¹, Ugur Aydin¹, Floran Martin¹, Reijo Kouhia², Anouar Belahcen¹, Antero Arkkio¹

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A novel approach for predicting magnetic hysteresis loops and losses in ferromagnetic laminations under mechanical stress is presented. The model is based on combining an energy-based anhysteretic magnetoelastic constitutive law to a vector Jiles-Atherton hysteresis model. The hysteresis loops and losses are modeled accurately for stresses ranging from -50 to 80 MPa.

ID: 33 / PB2: 2

Track 06

Topics: Material Modelling

Keywords: 3-D non-linear finite element method, hardened depth, surface hardening steel

Proposal of leakage flux inspection method for detecting hardened depth in surface hardened steel using 3-D nonlinear FEM

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The surface hardening steel is used for the many parts of engine or crankshaft in automobile. The inspection of the surface hardened depth is important in the intensity or the guarantee of quality of these parts. Especially, in order to raise the productivity of these parts, the non-destructive inspection method is needed for the evaluation of the hardened depth. The permeability and the conductivity of the hardened layer are smaller than the non-hardened layer in the steel. Therefore, the non-destructive estimation of the surface hardened depth is possible by using the differences of these electromagnetic properties. In this paper, the high sensitivity inspection method using the detecting of the leakage flux on the surface of the steel is investigated. The leakage flux is estimated by 3-D nonlinear finite element method (FEM) taking account of the magnetic characteristics of the layers with and without hardening. The usefulness of this proposal inspection method is shown also from comparison with a experimental verification.

ID: 77 / PB2: 3

Track 12

Topics: Material Modelling

Keywords: Finite element methods, hysteresis, magnetic materials, modeling.

A New Vector Hysteresis Model Based on Series-Distributed Play Hysteron

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This paper proposes a new vector hysteresis model based on series-distributed play hysteron. First, a new vector play operator is developed to satisfy the rotation loss property beyond saturation, which the ordinary vector hysteresis model fails to obey. Second, a variable recoil-line slope algorithm is introduced to more accurately represent individual minor loop behavior and to best match the measured minor loop. Then, to accommodate the proposed vector play operator and the variable slope algorithm, a series-distributed hysteron model is put forward. Finally, a detailed parameter identification procedure which is not only practical, but also computationally efficient is established. The presented model has been successfully implemented in 2-dimensional (2D) and 3-dimensional (3D) transient finite element analysis (FEA). Some application results are presented.

ID: 178 / PB2: 4

Track 17

Topics: Material Modelling

Keywords: Excess loss, finite difference method, Lagrange multiplier, loss separation.

Iron Loss Separation in High Frequency Using Numerical Techniques

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This paper proposes a tractable and robust numerical method to predict iron losses in electrical steel laminations subjected to high-frequency excitation. To achieve this goal, Preisach modeling and finite difference method (FDM) are firstly employed to simulate the hysteresis loss and the eddy current loss respectively. On this basis, a better approximation of the excess loss and its optimal parameter identification are achieved. All these efforts, with tolerable computational burden, reduces the errors between the estimated values and the measured ones, when compared to those obtained using conventional engineering models.

ID: 185 / PB2: 5

Track 18

Topics: Numerical Techniques, Material Modelling

Keywords: Finite element analysis, Inverse problem, Nondestructive testing, Numerical analysis, Gradient method

Reconstruction of Conductivity Distribution of Stress Corrosion Crack from DC Potential Drop Signals

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Concerning the safety influence of Stress Corrosion Crack (SCC), its quantitative Nondestructive Evaluation (QNDE) is significant to guarantee the structural integrity of nuclear power plants (NPPs). However, the NDE accuracy of SCC is still not satisfactory especially for the electromagnetic NDE methods such as Eddy Current Testing (ECT). The unknown conductivity distribution in crack region is one of the key factors restricting the precision enhancement for SCC sizing with ECT. As an effort to solve this problem, the conductivity distribution is investigated in this work through inversion of measured direct current potential drop (DCPD) signals. The inversion strategy, consisting of an efficient forward DCPD signal simulator using multi-medium element and the conjugate gradient optimization method, is proposed and implemented for the reconstruction of the conductivity distribution around the SCC region. The reasonable reconstruction results from measured DCPD signals of a SCC specimen validate the proposed scheme.

ID: 220 / PB2: 6

Track 14

Topics: Material Modelling

Keywords: Soft magnetic composite, homogenization, Ollendorff's formula, finite element method, magnetic circuit

Computation of Macroscopic Magnetic Properties of Soft Magnetic Composite Considering Non-uniformity

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It is revealed in this paper that consideration of non-uniformity in the particle size and thickness of the surface insulation layer is essentially important to accurately evaluate the macroscopic permeability of soft magnetic composite (SMC). It is shown that finite element method applied to a real picture image of SMC gives good approximation to its measured value while the homogenization method without considering the non-uniformity has significant errors. Moreover to evaluate the SMC permeability a simple magnetic-circuit method in which the non-uniformity is taken into consideration is proposed.

ID: 288 / PB2: 7

Track 11

Topics: Material Modelling, Multi-physics and Coupled Problems, Multi-scale modelling and homogenization

Keywords: Magnetostatics, nonlinear magnetics, magneto-mechanical couplings, hysteresis loops, multi-scale modeling

Incorporating Hysteresis at the Grain Scale of a Multi-Scale Material Model

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This paper proposes a multi-scale energy based material model for poly-crystalline materials. The model considers the polycrystalline, grain and crystal scales, exhibits magnetostriction and hysteresis and is merely based on a set of physical constants. The model is verified with existing measurement data for different stress levels and is found to provide a good accuracy.

ID: 321 / PB2: 8

Track 09

Topics: Material Modelling

Keywords: Magnetostriction, harmonic analysis, soft magnetic materials, magnetization, finite element analysis

Magnetostriction of Electrical Steel Sheet Under Different Magnetization Conditions

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Magnetostriction in non-oriented (NO) and grain-oriented (GO) electrical steel is a main source of vibration of iron cores in electrical machines and transformers. This paper presents the effect of different magnetization conditions, such as direct current biased magnetic field and higher harmonic field, on magnetostriction of a long strip of electrical steel sheet based on a one-dimensional (1-D) magnetostriction tester. The anisotropy of magnetostriction and the relation between principal strain and magnetic flux density was made clear by means of measured data. A vector model was proposed to describe the relationship mentioned above, and was applied to the magnetostrictive analysis of a synchronous machine.

ID: 461 / PB2: 9

Track 16

Topics: Material Modelling

Keywords: Magnetic materials, Nonlinear equations

A Surface Impedance Formula for Improved Computation of Eddy Current Loss in Nonlinear Magnetic Materials

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A new surface impedance formula for nonlinear magnetic materials is presented. It is shown to well predict the surface eddy current loss at all applied field amplitudes and for a wide range of commonly used materials. Compared to previously published formulas the accuracy is significantly improved across the intermediate transition range. Only two or three easily extracted parameters describing the BH curve are required, thus implying a minimum amount of pre-processing needed.

ID: 506 / PB2: 10

Track 11

Topics: Material Modelling

Keywords: Magnetic hysteresis, Eddy currents, Electromagnetic induction, Heat treatment

Equivalent permeability model to simplify the nonlinear hysteretic B-H curve in time harmonic FEM simulations of induction heating

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This paper addresses different levels of simplification for non-linear magnetic B-H curves intended to be used in induction hardening FEM simulations. The magnetic permeability is presented in the time domain and in the frequency domain. The error made by ignoring harmonic content in time harmonic simulations is quantified from a thermal point of view. Models such as the surface impedance and the co-energy density are shown. We present the idea of fitting an equivalent permeability from simulated results using the most detailed material properties available. Even magnetic hysteresis is taken into account thanks to an in-house FEM code. We calculate the power density distribution from eddy current losses and the temperature distribution for a given time period. The optimal magnetic permeability curve used in the frequency domain is fitted with a weighing function to mimic the temperature around crucial phase changes in steel.

ID: 528 / PB2: 11

Track 05

Topics: Numerical Techniques, Material Modelling

Keywords: Current distribution, equivalent circuit, magnetic hysteresis, superconducting cable.

Current Distribution Analysis for a Multilayer High-Tc Superconducting Cable Considering Magnetic Hysteresis

Weijie Xu^{1,2}, Nana Duan^{1,2}, Shuhong Wang¹, Jianguo Zhu², Youguang Guo²

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This paper presents a new Preisach type hysteresis model for the high temperature superconductor. This model requires only the limiting hysteresis loop as the input data, and for this model, the limiting hysteresis loop is firstly separated into two limiting M-H loops based on the mechanisms, which can then be modeled by two separate modified Preisach algorithms. The area integrations of the Preisach distribution functions are determined only based on the limiting M-H loops. The nonlinear dynamic circuit model of the superconductor is established. In the circuit model, the hysteresis inductance and hysteresis loss described by using the new Preisach type model are deduced. Applying the hysteresis circuit model, the currents flowing in different superconductor layers of high temperature superconducting (HTS) cable are simulated, as well as the hysteresis loss of the superconducting cable. The simulation results are verified by comparison with the data recorded in literatures. Finally, the influences of hysteresis on superconducting cable are analyzed and discussed.

ID: 566 / PB2: 12

Track 11

Topics: Material Modelling, Multi-scale modelling and homogenization

Keywords: Magnetic Losses, Composite materials, Effective properties, Electric conductivity

A Homogenization Strategy for Soft Magnetic Composites

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Soft magnetic composites (SMC) are a promising alternative to laminated steel in many Electrical Engineering applications. This is largely owing to their low level of eddy current losses. The electromagnetic behavior of SMC in electromagnetic devices cannot be easily predicted using standard numerical techniques such as the finite element method, mostly due to the computational cost required to model the material microstructure. Another difficulty lies in the high property contrast between the matrix and the inclusions. In this paper we propose a homogenization strategy to define the effective electromagnetic properties of SMC. These equivalent properties can be used to calculate eddy current losses or introduced into structural analysis tools to design electromagnetic devices.

ID: 596 / PB2: 13

Track 20

Topics: Numerical Techniques, Material Modelling

Keywords: Convergence of Numerical Methods, Finite Volume Methods, Iterative Algorithms, Numerical Simulation

Accurate Treatment of Nonconformal Material Interfaces in the Finite Integration Technique

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The Finite Integration Technique usually relies on a Cartesian mesh system whose planar facets in general don't coincide well with the simulated structure's material interfaces. This causes the simulation's error to be relatively high and, furthermore, degrades the method's convergence rate. This contribution proposes a generalized formula for representing the actual structure's material distribution on a discrete mesh system without compromising accuracy. In a second step, approaches to utilize the technically challenging generalized formula for practically relevant applications are demonstrated.

ID: 628 / PB2: 14

Track 16

Topics: Material Modelling

Keywords: Composite materials, effective electrical conductivity, inclusion, homogenization, finite element method (FEM)

Modeling of Electrical Percolation Threshold of Carbon Graphite Composite

Fiacre Djonkone SENGHOR, Guillaume WASSÉLYNCK, Didier TRICHET, Gérard BERTHIAU

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In this paper, a method to determine the effective electrical conductivity of composite constituted of two distinct phases with different physical property is presented. The conductive particles are randomly distributed in the thermoplastic polymer matrix. Homogenization method based on the equivalent representative volume is used to calculate the effective electrical conductivity. Results are then compared with analytical models based on the inclusion problem of Eshelby. The percolation threshold of the electrical conductivity is then discussed.

ID: 631 / PB2: 15**Track 11***Topics:* Material Modelling*Keywords:* magnetic materials, hysteresis, Preisach model**Closed Form Expression of Magnetic Hysteresis****Zsolt Szabó¹, János Füzi²**¹Budapest University of Technology and Economics, Hungary; ²Wigner Research Centre for Physics; szabo@evt.bme.hu

A closed form expression of magnetic hysteresis for arbitrary loops is derived based on the Preisach model. The Preisach function is considered as a product of two special one dimensional functions, which allows the analytical evaluation of the Everett integral. The derived expressions are included in static and dynamic hysteresis models, which prove to be fast enough to be incorporated in electromagnetic software. The applicability of the models are demonstrated fitting measured data.

ID: 701 / PB2: 16**Two Pages Short Version***Topics:* Numerical Techniques, Material Modelling*Keywords:* Magnetic materials, magnetization, nonlinear magnetics, permeability**A Rational Approach to B-H Curve Representation****Patrick Diez, Jon Webb**McGill University, Canada; patrick.diez@mail.mcgill.ca

The paper introduces an approach to constructing a rational function that fits the finite set of data points on the B-H plane representing the non-linear response of a permeable material, providing an approximation to the data well-suited for interpolation and extrapolation. Improving on previous methods, this approach provides a smooth, closed-form approximation to the data capable of representing the material's response from its Rayleigh region through to its saturation, appropriate for use with finite element solvers. This is achieved by applying the method of vector fitting (as seen in the discipline of control systems) to the B-H dataset, while taking care to remove pole-zero pairs that may occur between data points. The method is demonstrated to provide high-accuracy approximations to the datasets of a range of materials.

ID: 704 / PB2: 17**Two Pages Short Version***Topics:* Material Modelling*Keywords:* Graphic processing unit (GPUs), parallel processing, iron loss, Jiles-Atherton model, finite element method.**Implementation of Iron Loss Models on Graphic Processing Units****Sajid Hussain, Rodrigo Silva, David Alister Lowther**McGill University, Canada; david.lowther@mcgill.ca

Electromagnetic design engineers are always in search of extra computational power to finish their tasks at the earliest time. It is desired to optimize numerical data processing with all the computational power available. One way is to identify a part of the computation with a high degree of parallelism and then process it in graphic processing units (GPUs). GPUs are optimized to process such computations efficiently and quickly on multicore hardware. The steps involved in a finite element (FE) electromagnetic simulation are computationally very expensive. One such step is the communication between FE solver and the material loss model that takes place for every element in the mesh for each time step. This task is massively parallel and thus, can be implemented in GPUs. This work is a first step towards the implementation of material loss models in GPUs. A physics-based material model, Jiles-Atherton (JA) model, is implemented in GPU to compute the B-H hysteretic relationship which can be directly incorporated in FE simulation. The performance of the process is compared with the given microprocessor. It is concluded that the computational time can be greatly reduced with the help of GPUs.

ID: 705 / PB2: 18**Two Pages Short Version***Topics:* Material Modelling*Keywords:* Compressive Stress, electric machines, Iron Loss, Laminated steel, magnetic properties, single sheet tester.**Iron Loss Models under Static Stress for Non-Oriented and Grain Oriented Steel****Omar Saeed, Aroba Saleem, Tanvir Rahman, Richard Chromik, David Lowther**McGill University, Canada; david.lowther@mcgill.ca

Frequency domain iron loss prediction models have been developed taking the effects of mechanical stress into account. A Single Sheet Tester (SST) was used for non-oriented and grain oriented steels to apply up to 40 MPa stress (along the longitudinal direction) for frequencies ranging from 100 Hz to 1000 Hz. Both compressive and tensile stresses were applied. It was shown that the effects on core loss and magnetic permeability is greatest under compressive stress. Using the results of the experiments two modern frequency domain loss models were considered and modified to include the effects of stress. The variation of the model coefficients as a function of stress was studied and it was shown that the hysteresis component of the loss model varies significantly compared to the eddy loss component which is in line with expectations. The accuracy of the loss prediction models were found to be better than 3% for sinusoidal waveforms over the frequency range and for saturation level up to 1.6 T.

PB3: Software methodology; Education

Time: Tuesday, 30/Jun/2015: 10:30am - 12:15pm · *Location:* Lounge

Session Chair: Jean Bigeon

Session Chair: Sheppard Salon

ID: 34 / PB3: 1

Track 18

Topics: Optimization and Design, Mathematical Modelling and Formulations, Numerical Techniques, Software Methodology

Keywords: CUDA, GPU, FEM, assembly, sorting

Towards real-time finite element simulation on GPU

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In this paper, we introduce a parallel assembly technique on NVIDIA CUDA GPUs for finite element method (FEM) applied in the magnetic field computation. Basically, each thread calculates the integration associated with an element. To avoid memory conflicts, we introduced a fast procedure based on row sorting and rearrangement of elementary non-zero (NZ) entries. Finally, a reducing process by row is executed to assemble NZ in the stiffness matrix. This algorithm does not require any preprocessing on mesh but also take advantage of parallel computing power of GPU through load balancing. In our tests, using this parallel assembly improved the speed assembling up to 20x times faster.

ID: 57 / PB3: 2

Track 20

Topics: Numerical Techniques, Software Methodology

Keywords: boundary element methods, fast multipole methods, isosurfaces, meshfree methods

A meshfree isovalue search method for boundary element methods

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An efficient isovalue search method is a prerequisite for the computation of isosurfaces, which are an established approach to visualize scalar fields or the absolute value of vector fields in three dimensions. A classical method to make volume data available in the case of boundary element methods is to precompute the values of the examined field in the nodes of an auxiliary post-processing volume mesh and to interpolate the field values with linear shape functions. Then, an octree scheme is applied to find volume elements, which are intersected by the isosurface. Finally, the surface elements of the isosurface are constructed using the intersection points of the isosurface with the volume elements. The accuracy and the computational costs are mainly influenced by the density of the volume mesh. Here, the applicability of a meshfree approach for the isovalue search is investigated. An octree-based search method is directly coupled to the octree-based fast multipole method. Then, needed field values are obtained from an evaluation of higher order polynomials in spherical coordinates. Thus, a high accuracy of the isovalue search is achieved along with relatively low computational costs.

ID: 387 / PB3: 3

Track 12

Topics: Software Methodology, Multi-physics and Coupled Problems

Keywords: Open source software, Modeling, Finite element analysis, Education.

ONELAB: Bringing Open-Source Simulation Tools to Industry Design and Education

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We present the ONELAB software, a lightweight open source toolkit to interface finite element and related solvers used in a variety of engineering disciplines, and to construct multi-code models with maximum flexibility, efficiency and user-friendliness. ONELAB is freely available at "<http://onelab.info>".

ID: 416 / PB3: 4

Track 09

Topics: Software Methodology

Keywords: Magnetic field, Magnetic flux line, Probability distribution, Visualization

Magnetic Flux Line Allocation Algorithm Using Magnetic Flux Line Existence Probability for Magnetic Flux Visualization

Takuto Naoe, So Noguchi, Hajime Igarashi

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The visualization of magnetic flux lines is one of the effective ways of observing a magnetic field. In the visualization of magnetic flux lines, it is necessary that the allocation of magnetic flux lines is determined according to the magnetic flux density. We have previously proposed two methods of determining the allocation of magnetic flux lines in 3-D space. However, both methods take a long computation time to determine the allocation of magnetic flux lines, because the Bubble System is utilized. For solving the problem, in this paper, we propose a method of shortly and appropriately allocating magnetic flux lines for depicting. In the proposed method, the magnetic flux line existence probability is employed. The proposed method takes much shorter time than the previously proposed methods. Moreover, it also takes a short time to redraw the magnetic flux lines when their number is changed.

ID: 525 / PB3: 5

Track 09

Topics: Education

Keywords: Computer aided instruction, Courseware, Electrical engineering education, Open source software

Tools for Visualizing Cuts in Electrical Engineering Education

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We study visualization of electromagnetic (EM) phenomena from an educational viewpoint. We exploit software and 3D printing for visualization and exemplify their usage to enhance student learning.

Our focus is on so called cuts which highlight important topological information in EM problems. We also discuss conceptual and historical advances on topological features of EM problems.

ID: 580 / PB3: 6

Track 12

Topics: Software Methodology

Keywords: High performance computing, Space charge, Parallel algorithms, Partitioning algorithms, Computational efficiency

A PARALLEL PARTICLE-IN-CELL CODE FOR HETEROGENEOUS HARDWARE

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An evaluation for a parallel Particle-In-Cell code leveraging heterogeneous hardware is presented. Two parallelization strategies are investigated on Intel Xeon Phi coprocessors. Hybrid parallelization is implemented to support optional workload offloading to coprocessors. A performance model is applied to load balance heterogeneous setups. Performance measurements of a benchmark show the quality of the proposed load balancing for both parallelization strategies.

ID: 700 / PB3: 7

Two Pages Short Version

Topics: Software Methodology

Keywords: Mesh; MapReduce; MPI; Finite Element Method.

A MapReduce and MPI Programming Model for Distributed Large Scale 3D Mesh Processing

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Developing a high performance platform for large-scale, high-intensity data processing is a priority for researching cost-effective parallel finite element methods (FEM). This paper introduces an efficient MapReduce-MPI based strategy for parallel 3D finite element mesh processing, demonstrates the potential benefits of this approach for optimally utilizing system resources. Preliminary experimental results show that the new platform improves speedup over a range of problem sizes and different machine numbers. In detail, this paper includes the design of scalable Hadoop algorithms for 3D FEM mesh processing; experimental evaluation of these algorithms on computer clusters; and discussions on the benefits and challenges of developing 3D FEM algorithms using the MapReduce-MPI model.

PB4: Optimization and design 2

Time: Tuesday, 30/Jun/2015: 1:45pm - 3:25pm · *Location:* Cafeteria

Session Chair: Hyun-Kyo Jung

Session Chair: Joao Pedro Assumpcao Bastos

ID: 46 / PB4: 1

Track 13

Topics: Optimization and Design

Keywords: Evolutionary computing, multiobjective optimal design, sensitivity analysis, finite elements, magnetic field synthesis.

Switch of design variables: a cost-effective identification of the Pareto front in inverse magnetics

Paolo Di Barba¹, Fabrizio Dughiero², Michele Forzan², Elisabetta Sieni²

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A new optimization method, combining design of experiments with evolutionary computing, is proposed: it handles a set of design variables, the size of which changes during the process: initially, most sensitive variables are activated; subsequently, the whole set of variables is activated. The optimal synthesis of a magnetic field for magneto-fluid treatment is considered as the case study.

ID: 51 / PB4: 2

Track 14

Topics: Optimization and Design

Keywords: Biogeography inspired optimization, Pareto optimality, MEMS, electrostatic field, finite-element analysis

Biogeography-inspired multiobjective optimization and MEMS design

Paolo Di Barba¹, Maria Evelina Mognaschi¹, Antonio Savini¹, Slawomir Wiak², Fabrizio Dughiero³

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The paper proposes a new version of the biogeography-based optimization algorithm in order to take into account multiple objectives: in fact, by exploiting non-dominated sorting of habitats, it is possible to approximate Pareto-optimal solutions in the objective space. The optimal shape design of an electrostatic micromotor, which is a benchmark in MEMS design, is considered as the case study.

ID: 90 / PB4: 3

Track 01

Topics: Optimization and Design

Keywords: Electromagnetics, optimization, reliability theory, robustness

A Comparative Study on Probabilistic Optimization Methods for Electromagnetic Design

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A reliability-based robust design optimization (RBRDO) is developed to ensure the product quality as well as the confidence in product reliability of electromagnetic devices. In the method, the first two statistical moments, mean and variance, of a quality loss function is estimated by the univariate dimension reduction method (DRM), while desired probabilistic constraint conditions is assessed by the first-order reliability analysis method. For better understanding between probabilistic optimization methodologies, three different formulations of reliability-based design optimization (RBD), robust design optimization (RDO) and RBRDO are presented and compared with each other. A simple mathematical design problem is tested to demonstrate the features of the three methods and to examine their numerical efficiency.

ID: 127 / PB4: 4

Track 01

Topics: Optimization and Design

Keywords: Design optimization, probability, possibility theory, reliability

A Novel Possibility-based Robust Optimal Design Algorithm in Preliminary Design Stage of Electromagnetic Devices

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In the early design stage of an electromagnetic device, sufficient information on uncertainties in design variables is not available. Therefore, a reliable optimal design through conventional reliability analysis by probabilistic method cannot be achieved. This paper, only with insufficient uncertainty data, proposes a new possibility-based optimal design algorithm to get a robust and reliable optimal design of electromagnetic devices. The suggested algorithm adopts a possibility analysis utilizing fuzzy set theory. The possibility analysis employs a surrogate model constructed by design sensitivity analysis to mitigate expensive performance analysis. Finally, the developed optimal design algorithm is validated through applications to several examples.

ID: 163 / PB4: 5

Track 02

Topics: Optimization and Design

Keywords: Ferrite magnet motor, Level set method, Rotor design, Sensitivity analysis, Topology optimization

Topological Design Sensitivity Analysis for Ferrite Magnet Motor Design

Youngsuk Jung, Seungjae Min, Jung-Pyo Hong

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This paper presents a ferrite magnet motor design by considering the topological design sensitivity of a multi-material structure. The permanent magnet synchronous motor (PMSM) with a rare-earth magnet has been widely used in industrial fields due to its high power density. However, the unstable rare-earth magnet supply rate is causing its price to fluctuate; hence, a design technique for replacing the rare-earth magnet with a ferrite magnet in PMSM has recently become a critical issue. To achieve this, an optimization method has to be conducted in the design stage of the motor to achieve target performance since the residual flux density of the ferrite magnet is about one-third of that of a rare-earth magnet. Therefore, there has been a research effort to determine the optimal shape of the magnet by implementing heuristic or parametric optimization. A level-set based topology optimization technique is introduced to determine the drawbacks of heuristic or parametric optimization methods such as dependence on the initial shape and lack of detailed representation of the boundaries. For multi-material structure design, N level set functions are required to represent $2N$ different materials. Therefore, two level-set functions are required to design a ferrite magnet motor consisting of three different materials: a permanent magnet, ferromagnetic material, and air. Six cases are revealed with different sensitivity values depending on the selection of the material domains. To compare the six different cases, an optimization problem is formulated that minimizes the sum of the difference of the target torque. It is confirmed that the selecting material domain, which has a low difference value of sensitivity and both level-set functions having the same direction, is a requirement to achieve optimum design with better performance and better convergence

ID: 226 / PB4: 6

Track 02

Topics: Optimization and Design

Keywords: Differentially coupled, finite element method, multi-degrees-of-freedom, electromagnetic actuator

Characteristics Analysis of a 2-D Differentially Coupled Magnetic Actuator Employing 3-D FEM

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In multi-degree-of-freedom systems, a number of motors are used to achieve a multi-DOF motion. However, these systems have problems such as heavy weight, large size and no back drivability due to large number of motors. In order to solve the problems, there have been many works to achieve multi-DOF motions using 1 actuator. In this paper, a novel 2-DOF differentially coupled magnetic actuator is proposed and its structure and operating principle are described. Finally, the static force and torque characteristics are computed by employing 3-D FEM.

ID: 262 / PB4: 7

Track 14

Topics: Optimization and Design

Keywords: Finite element method, high torque-density, magnetic gear, optimization, permanent magnet

Design Optimization and Comparison of High Torque-Density Magnetic Gears

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High torque-density magnetic gear (MG) is a new type of magnetic device that has great potential to be utilized in various fields of industries. However, with limited supply and high fluctuating costs of permanent magnet (PM) materials, the optimized design of MGs is vital and necessary. This paper presents several topologies of MGs and their structures are optimized and the torque densities are compared. An optimal design method based on genetic algorithm (GA) and finite element method (FEM) is proposed for the comparison of MGs.

ID: 265 / PB4: 8

Track 01

Topics: Optimization and Design

Keywords: Decision making, heuristic algorithms, inverse problems, Pareto optimization.

An Improved Light Beam Search Method for Multiobjective Optimizations of Inverse Problems

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An improved light beam search method is proposed to solve multiobjective designs of inverse problems. To guarantee a uniform distribution of the searched Pareto solutions, the utopia plane (line) is divided into sub-domains and an evaluation mechanism is proposed to identify the topology relationship between each individual and the preference zone. To avoid pre-mature and to enhance the diversity of the population, a multi-external achieves methodology is proposed, with the goal of using different achieve in the mating pool evolutionary process in different searching stages of the algorithm. Mathematical test functions and a benchmark inverse problem, TEAM Workshop Problem 22, are used to testify the effectiveness and the efficiency of the proposed method. The results demonstrate that the proposed method can obtain well distributed Pareto solutions under the predefined directions of the decision maker's reference with a less iteration number.

ID: 268 / PB4: 9

Track 07

Topics: Optimization and Design

Keywords: Inverse problem, robust optimization, stochastic approximation, tabu search method, uncertainty.

A New Methodology for Robust Optimizations of Inverse Problems under Interval Uncertainty

Shiyong Yang, Jiaqiang Yang, Yanan Bai, Guangzheng Ni, Jianhua Wu

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To consider the interval uncertainty in a practical inverse problem, a new methodology for efficient robust optimizations is proposed. The proposed methodology uses a constrained formulation for robust performances not only in alleviating the inefficiency of existing approaches in modeling interval uncertainties but also in avoiding the deficiency in the biasing force selection. The gradient information is used as both a trigger to activate the uncertain quantification procedure and the steepest increment direction to develop a fast searching phase. The stochastic approximation method is employed to minimize the computational burdens in computing the gradients. The numerical results on a case study are reported to validate the proposed methodology.

ID: 295 / PB4: 10**Track 07***Topics:* Optimization and Design*Keywords:* Topology optimization, Hybrid magnetic torque converter (MTC), Box-Behnken design (BBD), Multiple regression analysis, Analysis of variance (ANOVA), Response surface analysis.**Topology Optimization of Hybrid Magnetic Torque Converter based on Box-Behnken Design****Sung-Jin Kim¹, Chan-Ho Kim¹, Sang-Yong Jung², Yong-Jae Kim¹**¹Chosun University, Korea, Republic of (South Korea); ²Sungkyunkwan University, Korea, Republic of (South Korea);kimchanho@chosun.kr

This paper derives an effective shape by topology optimization of hybrid magnetic torque converter (MTC) based on Box-Behnken design (BBD). Analysis between independent variable selected by BBD and reaction variable using the finite element method (FEM) based on 2-D numerical analysis. Also, regression equation of reaction variable according to the independent variable by multiple regression analysis and analysis of variance (ANOVA) derived and validity of optimization design by comparing characteristics optimized model derived from response surface analysis and initial model demonstrated.

ID: 306 / PB4: 11**Track 13***Topics:* Optimization and Design*Keywords:* Line start permanent magnet motor, Finite element analysis, Optimization**Optimal Rotor Shape Design for Performance Improvement of Line Start Permanent Magnet Motor****Subrato Saha, Sung-An Kim, Yun-Hyun Cho**Dong-A University, Korea, Republic of (South Korea); shuvo4279@gmail.com

Recently Line Start Permanent Magnet Motor (LSPM) is a well-known motor due to its technical advantages in academic and industrial sector. The LSPM combines a permanent magnet rotor that allows higher motor efficiency during synchronous operation, and an induction motor squirrel cage rotor for starting the motor by connecting it directly to an A.C. Source. In this paper, we will deal with the efficiency and Power factor improvement of a 3.4kW, 2-pole, three-phase LSPM using the difference in d-axis magnetic inductance (L_d) and q-axis magnetic inductance (L_q). d-axis and q-axis magnetic inductance are nonlinear problem which are varied with current level and current angle. Therefore, nonlinear finite element analysis is necessary to obtain the L_d and L_q. The efficiency improvement can be effectively achieved by designing optimization of the rotor structure using finite element method. The optimized slot shape of PM was selected for the prototype machine, which improves the efficiency and power factor of LSPM.

ID: 394 / PB4: 12**Track 07***Topics:* Optimization and Design, Numerical Techniques*Keywords:* Moving least square approximation, optimization method, particle swarm optimization, radial basis function, response surface model**A Dynamic Dual-Response-Surface Methodology for Optimal Design of a Permanent-magnet Motor Using Finite-element Method****Xiaoyu Liu, Weinong Fu**

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This paper proposes a novel strategy to accelerate the optimization process for designing a permanent-magnet (PM) motor. In order to compute an objective function, a finite-element method (FEM) with the assistance of a dynamic dual-response-surface model (dual-RSM) is presented. The FEM serves as a basic tool to compute the objective function and at the same time, its results are used to train the dual-RSM model. A radial basis function (RBF) and a moving least square (MLS) approximation are both employed to build up the dual-RSM model. The results which are obtained from the dual-RSM model are dynamically compared together with the results from the FEM, which determines whether the accuracies of the dual-RSM are high enough to replace the FEM computation. This strategy makes the FEM computation not always required at every sample point in the optimization process while ensures the accuracies of RSM. The optimal design of a permanent-magnet (PM) synchronous motor is taken as an example to demonstrate the effectiveness of the proposed optimization methodology. Comparing with traditional optimal method which only uses FEM for the evaluation of the objective function, the proposed method can dramatically reduce the computing time.

ID: 660 / PB4: 13**Track 07***Topics:* Optimization and Design*Keywords:* Brushless machines, Finite element analysis, Optimization**Interstella Search Method with Mesh Adaptive Direct Search for Optimal Design of Brushless DC Motor****Byungkwan Son¹, Gyeong-Jae Park¹, Jong-Wook Kim², Sang-Yong Jung¹**¹Sungkyunkwan University, Korea, Republic of (South Korea); ²Dong-A University, Korea, Republic of (South Korea);byeongkwani@naver.com

In this paper, a novel global search algorithm 'Interstella Search Method' (ISM) and its hybridization with Mesh Adaptive Direct Search (MADS) is proposed. ISM is population-based algorithm and is suitable for multimodal function, because of its capability to find diverse target islands of local optima in a short time. The hybridization with MADS support the fast convergence to local optima from target islands that are discovered in global search using ISM. The effectiveness of ISM was verified through the test function and compared with Genetic Algorithm and Particle Swarm Optimization. Lastly, ISM was applied to optimal design of Brushless DC motor based on Finite Element Analysis.

ID: 670 / PB4: 14**Track 05**

Topics: Optimization and Design

Keywords: Cyclotron, Magnetic field, Sequential Approximation Techniques, Kriging, Restricted Evolution Strategy.

Design Optimization of 10 MeV Cyclotron Magnet Using the Sequential Approximation Technique

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The systematic process of design optimization was proposed by using the sequential approximation technique for a 10 MeV cyclotron magnet, which is a Positron Emission Tomography (PET) cyclotron for producing radioactive isotopes. The aim of this optimization process is to reduce the size of magnet while producing radioisotopes efficiently with the minimization of beam loss. For optimization process, here, we adopted the Latin Hypercube Sampling (LHS) method, one of design of experiments (DOE), and generated sampling data. And based on these data, an approximation model was modeled by using the Kriging technique. To find out an optimal shape, an iterative searching technique was implemented incorporating with the approximation model and the Restricted Evolution Strategy (RES). The initial magnet model was obtained from the conventional routine procedure for cyclotron. To verify our proposed model, the final magnet model was tested with the beam simulation for checking the trajectory of ^{18}F with the level of 10 MeV at the extraction point.

ID: 703 / PB4: 15

Two Pages Short Version

Topics: Optimization and Design

Keywords: Multi-Objective Optimization, Robust Optimization, Design Optimization

On the Role of Robustness in Multi-Objective Robust Optimization in the Design of Electromagnetic Devices

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This paper describes the different roles that robustness can assume when solving a multi-objective design optimization problem. A new role for robustness is proposed based on which an approach to conducting multi-objective robust optimization and finding the optima is suggested. This new approach is then tested on an analytical problem and the results are presented.

ID: 547 / PB4: 16

Track 01

Topics: Optimization and Design

Keywords: Continuum shape sensitivity, Electrostatic system, Optimization, Topology sensitivity formula, Virtual hole

Hole Sensitivity Analysis for Topology Optimization in Electrostatic System Using Virtual Hole Concept and Shape Sensitivity

Kang Hyouk Lee, Seung Geon Hong, Myung Ki Baek, Il Han Park

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In this paper, the hole sensitivity formula for topology optimization in electrostatic system is derived using the continuum shape sensitivity and the virtual hole concept. The hole sensitivity gives additional information to guide the searching direction of the optimization to the global minimum. The hole sensitivity formula is the simple closed form. The shape and hole sensitivity provides the direction of topology variation and the variation is represented by the level set method with finite element method. The numerical example is tested and are compared to prove the usefulness of the hole sensitivity in electrostatic system.

ID: 200 / PB4: 17

Track 07

Topics: Optimization and Design

Keywords: Design sensitivity analysis, adjoint variable method, direct method, continuum approach, magnetostatic system, shape optimization

Design Sensitivity Analysis for Shape Optimization of Nonlinear Magnetostatic Systems

Erin Kuci^{1,2}, Pierre Duysinx¹, Patrick Dular², Christophe Geuzaine²

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In this paper, a direct and an adjoint analytic sensitivity analysis for a nonlinear magnetostatic system is obtained, in the context of shape optimization for any design function. The calculations are based on the material derivative concept of continuum mechanics. The resulting sensitivity formula can be expressed as either a volume integral or as a boundary integral along the interface where shape modification occurs. A method for the calculation of the design velocity field and mesh updating scheme is introduced as well. The accuracy of the methodology is analysed on an inductor system, suggesting that the volume integration technique should be preferred. All methods are freely available for further testing in the open source environment GetDP/Gmsh.

ID: 583 / PB4: 18

Track 01

Topics: Optimization and Design

Keywords: genetic algorithms, sensitivity analysis, design optimization, finite element analysis, electromagnetic fields, microstrip

Reduction of optimization problem by combination of optimization algorithm and sensitivity analysis

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A special optimization technique based on combination of genetic algorithms and sensitivity analysis is proposed. The technique allows reducing the number of optimized parameters during the optimization process and, consequently, the time of optimization. The paper explains the principle and benefits of the algorithm and illustrates its utilization with a illustrative example. The algorithm is implemented in the framework OptiLab that represents a part of the application Agros2D developed by the authors.

ID: 605 / PB4: 19

Track 14

Topics: Optimization and Design

Keywords: Dot sensitivity, Free initial design, Topology optimization, Adaptive level set method, Magnetostatic system

Dot Sensitivity Analysis of Ferromagnetic Material for Initial-Design-Free Topology Optimization in Magnetostatic System

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The hole sensitivity analysis was recently developed to solve the problem of topology simplification with design optimization process. However, the hole sensitivity analysis may fall into a local optimum because it cannot generate new design material in a vacant region, and an initial topology of design material should be given by designer. This paper presents a novel topology optimization method of dot sensitivity analysis to solve the above mentioned problems. The dot sensitivity is derived in an analytic form by using continuum shape sensitivity, and the adaptive level set technique is described for its numerical technique. Finally, the obtained dot sensitivity and the level set method are applied to two design problems to show its usefulness.

PB5: Numerical techniques 1

Time: Tuesday, 30/Jun/2015: 1:45pm - 3:25pm · *Location:* Lounge

Session Chair: André Buchau

Session Chair: Francis Piriou

ID: 55 / PB5: 1

Track 08

Topics: Numerical Techniques

Keywords: Magnetic saturated PECT, Nonlinear, Numerical method, Carbon steel, Nondestructive evaluation

Nonlinear Numerical Method for Simulation of Magnetic Saturated Pulsed Eddy Current Testing Signals and Its Application to Evaluation of Wall Thinning in Carbon Steel Piping

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Quantitative non-destructive evaluation of wall thinning in carbon steel piping is a difficult and urgent issue for safety of nuclear power plants. A magnetic saturated PECT (pulsed eddy current testing) method has been proposed by authors for this purpose, where an electromagnetic magnet is utilized to generate strong static magnetic field to saturate the piping material, i.e., to increase the skin depth, and the PECT is applied then in the magnetic saturated environment. To evaluate the feasibility of the magnetic saturated PECT method for wall thinning detection in carbon steel piping, numerical method for simulation of nonlinear PECT signals is proposed and validated in this study. Firstly, the simulated magnetic polarization approach is adopted for the calculation of the static magnetic field distribution generated by the electromagnetic magnet, and the local permeability distribution is predicted then according to the local magnetic flux density and the B-H curve. Finally an nonlinear PECT forward simulation tool is developed based on the reduced A method and step by step numerical integration strategy, and is applied to validate the magnetic saturated PECT method for evaluation of wall thinning defects in carbon steel.

ID: 61 / PB5: 2

Track 10

Topics: Static and Quasi-Static Fields, Optimization and Design, Numerical Techniques

Keywords: Poisson's equation, FFT, beam dynamics, space charge.

A Fast Poisson Solver for 3D Space Charge Calculations in a CPU+GPU Heterogeneous Routine

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Space charge calculations play a key role in beam dynamics studies for particle accelerators. The major work is to solve Poisson's equation for many time steps. Therefore, it is important to solve Poisson's equation in a short time. In this paper, we present the different Green's functions, an efficient discrete cosine transform rather than the former discrete Fourier transform and the corresponding CPU+GPU heterogeneous routine for the Poisson solver. A model problem has been studied which showed an efficiency improvement with the new heterogeneous routine.

ID: 73 / PB5: 3

Track 13

Topics: Static and Quasi-Static Fields, Mathematical Modelling and Formulations, Numerical Techniques, Multi-physics and Coupled Problems

Keywords: Induction heating, Eddy currents, Nonlinear dynamical systems, Model order reduction, Volterra series

Fast Solution of Induction Heating Problems by Structure Preserving Nonlinear Model Order Reduction

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A fast approach to the numerical solution of induction heating problems, exploiting a novel nonlinear Model Order Reduction technique, is proposed. The problem equations are rewritten in an equivalent way in which only quadratic nonlinearities occur. Projecting these equations in such a way to preserve their nonlinear structure, a reduced nonlinear model is directly constructed. The projection space is attained by numerically computing a few of the first kernels in the Volterra series expansion of the solution to the induction heating problem. Numerical results show that the construction of the proposed reduced nonlinear model is performed at a computational cost which is about one order of magnitude less than that of a standard approach. The reduced model solution is numerically performed at negligible computational cost and allows to reconstruct the whole space-time distribution of the coupled electromagnetic and thermal field, with high accuracy.

ID: 102 / PB5: 4

Track 07

Topics: Static and Quasi-Static Fields, Numerical Techniques

Keywords: adaptive strategy, leader propagation model, lightning shielding failure, lightning protection, transmission line

Adaptive Strategies in the Leader Propagation Model for Lightning Shielding Failure Evaluation: Implementation and Applications

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Lightning is the major cause of unexpected outage in electric transmission systems, among which lightning shielding failure accounts for the most proportion of the lightning accident for transmission systems above 500 kV. The leader propagation model was found to be effective to the analysis of lightning shielding failure of high voltage transmission lines, especially for the UHV

transmission systems. However, it was generally slow to calculate the shielding failure rate by LPM because the progress of lightning development must be calculated repeatedly, which required large amount of computation. In this paper, adaptive strategies to accelerate the computation of LPM were proposed. The computation results were validated by the field data of the Japanese UHV

transmission line and a typical 500kV AC transmission line.

ID: 195 / PB5: 5

Track 02

Topics: Optimization and Design, Numerical Techniques

Keywords: Electromagnetic fields, Perturbative methods, Numerical simulation, Cavity resonators, Design Optimization

Investigation of Geometric Variations for Multicell Cavities Using Perturbative Methods

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The design of multicell accelerator cavities is a challenging task since it implies the manipulation of various shape parameters regarding different (partially contradicting) optimization goals. Simulating the electromagnetic (EM) characteristics of the full structure depending on various geometric parameters typically involves an enormous computational effort. In most cases, this limits the observed frequency range and the number of optimization passes. Despite the fact that effects of unintended shape deviations are usually excluded from optimization processes, they may be of particular importance for the final design.

Perturbative methods offer an efficient approach to tackle this issue. They allow for the computation of the eigenmodes and the derived cavity performance parameters for a vast number of cavity designs based on one initial design. In this contribution, we investigate the applicability of perturbative methods for performance optimization and simultaneous consideration of shape variations of a multicell structure.

ID: 198 / PB5: 6

Track 20

Topics: Numerical Techniques

Keywords: Reduced-order systems, finite-element analysis, iterative methods, phased arrays.

An Adaptive Deflation Domain-Decomposition Preconditioner for Fast Frequency Sweeps

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Adaptive multi-point model-order reduction is a well established methodology for computing fast frequency sweeps of finite-element models. However, in the case of electrically large structures, generating the reduced-order system is computationally expensive, because both the size of the finite-element model and the number of expansion points become large.

Thus, a great number of independent large-scale systems of linear equations must be solved by iterative methods.

To alleviate this problem, the present paper proposes to employ the reduced-order system already available at a given adaptive step for constructing an efficient two-level preconditioner.

A numerical example demonstrates the benefits of the suggested approach.

ID: 228 / PB5: 7

Track 14

Topics: Numerical Techniques

Keywords: Conjugate gradient method, Deflation method, Multigrid method, Topology optimization

Fast Linear Solver Using Deflation Method and Multigrid Method for Optimization

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Fast linear solvers for shape optimization using a deflation technique and a multigrid method are discussed. The optimization method based on evolutionary algorithms such as a genetic algorithm requires huge computational cost to evaluate many trial shapes. In this reason, a deflated preconditioned conjugate gradient (PCG) method is introduced so as to reduce the cost of finite element analysis which is used to evaluate the objective function. The deflation technique decomposes the solution into fast and slowly components. The slowly components can be solved by direct methods with low computational cost due to small dimensions. Therefore the deflated PCC method can improve the convergence of PCG. However, the deflated PCG requires eigenvectors which have high computational cost. In this study, a multigrid method is introduced to solve this difficulty. Instead of the high cost eigenvectors, eigenvectors of the system matrix on a coarse mesh are used for the deflation method. The computational cost to obtain them is low because the system matrix on the coarse mesh is small. Thus the proposed method can reduce the computational cost. Numerical results show that the present method can improve the convergence and reduce the computational cost of optimizations.

ID: 250 / PB5: 8

Track 18

Topics: Numerical Techniques

Keywords: Auxiliary differential equation (ADE), Dispersive media, Weighted Laguerre polynomials, Factorization-splitting scheme

FS-ADE-WLP-FDTD Method for Calculating Wave Propagation in General Dispersive Materials

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Within the framework of the finite-difference time-domain (FDTD) and the weighted Laguerre polynomials (WLPs), we derive an effective update equation of the electromagnetic in the dispersive media by introducing the factorization-splitting (FS) schemes and the auxiliary differential equation (ADE). As an example, we employ a 2-D parallel plate waveguide loaded with two dispersive medium columns to calculate the plane wave propagation by using the ADE- FDTD method, the ADE-WLP-FDTD method and the FS-ADE-WLP-FDTD method. Results show that the FS-ADE-WLP-FDTD method is more accurate and effective.

ID: 301 / PB5: 9

Track 02

Topics: Numerical Techniques

Keywords: Linear system, GPGPU, High performance computing

Acceleration of Iterative Solver for Electromagnetic Analysis using GPU/MIC

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The mixed precision variable preconditioning (VP) Krylov subspace method is implemented on Graphics Processing Unit (GPU) and Many Integrated Core (MIC) architecture, and the linear system obtained from an electromagnetic analysis is solved by the method. In recent year, high-performance multi/many core computer architecture can be cheap and easily available, and the simulation code must be parallelized by using parallelization API. Although the ordinal program code that developed on CPU can be implemented on MIC without transcribing, GPU programming cost using CUDA becomes very high. In the present study, the performances of the mixed precision VP Krylov subspace method on GPU and MIC are compared by solving the linear system obtained from electromagnetic analysis discretized by edge element. The results of computation show that the communication cost of MIC is much higher than that of GPU.

ID: 423 / PB5: 10

Track 04

Topics: Static and Quasi-Static Fields, Numerical Techniques, Novel Computational Methods for Machines and Devices

Keywords: Approximation methods, computational electromagnetics, finite element analysis, nonconforming mesh.

3D FEM analysis of static fields for nonconforming meshes with node-based, 2nd order elements

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The novel approach of using node-based, second order polynomial shape functions to substitute the degrees of freedom corresponding to slave nodes by a linear combination of those corresponding to master nodes is shown to be a powerful and accurate tool to couple

nonconforming meshes. This method is investigated and proposed to be used to take moving domains, especially rotating parts into account. In addition, it is shown that, in comparison to consistent meshes, the number of finite elements can be decreased without any loss of accuracy.

ID: 517 / PB5: 11

Track 19

Topics: Static and Quasi-Static Fields, Numerical Techniques

Keywords: GPUs, HPC, integral formulation, NDT, fusion plasma devices

Speed-up of magnetic-electric matrices assembly computation by means of a multi GPUs environment

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This paper deals with an accelerated implementation of the assembly of the matrices accounting for the magnetic-electric interactions arising from an integral formulation of the magneto-quasi-static problem. The use of integral formulations leads to fully populated matrices whose computational effort is $O(N^2)$, N being the number of degrees of freedoms (DoFs) related to the finite element mesh. Although the inversion procedure is $O(N^3)$ for a direct solver, for "medium size" problems the assembly can be very time consuming, especially when a great accuracy is required and/or a great deal of geometrical details should be investigated. In this work we will prove that a significant speed-up can be achieved by means of an "ad-hoc" use of GPUs, although its implementation is really challenging w.r.t. the traditional parallel computational systems. Two kinds of applications are shown: one in framework of Non-Destructive Testing (NDT), the other in the field of plasma fusion devices modelling.

ID: 652 / PB5: 12

Track 04

Topics: Numerical Techniques

Keywords: Discontinuous Galerkin method, Explicit Runge-Kutta (ERK) schemes, Maxwell equations, Multirate technique

Multirate technique for explicit Discontinuous Galerkin computations of time domain Maxwell equations on complex geometries

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The computing of electromagnetic waves in complex geometries have to face the problem due to using of small size elements in the generated meshes. This affect convergence criteria of classical explicit numerical schemes. This paper presents a multirate technique to improve and optimize the time step of the ERK methods. In this technique, firstly the mesh elements are stored in different groups according to their stable time steps. These groups are sorted in two classes. The bulk groups where the classical second order 2-stages ERK methods are applied and the buffer groups that served to accommodate transition between two bulks groups. The 2-stages ERK methods are adapted to satisfy the conservations properties during the communication between the groups. This technique is developed for accelerating explicit discontinuous Galerkin computations of time domain Maxwell equations. An application example on human skull is proposed to show efficiency of this technique to simulate wave propagation on complex geometries

ID: 674 / PB5: 13

Track 04

Topics: Static and Quasi-Static Fields, Numerical Techniques

Keywords: Numerical analysis, finite element analysis, numerical simulation, domain decomposition method (DDM), radial basis function (RBF)

Hybrid Approach of Radial Basis Function and Domain Decomposition Method based on FEM with Different Shape of subdomains for Electromagnetic Problems

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A novel approach, namely radial basis function (RBF) mixed with domain decomposition method (DDM) based on Galerkin finite element method (FEM) has been introduced in previous paper. The proposed method divided the computational domain into a series of rectangular subdomains, and each subdomain as a separate calculation area gets the solution expression and shape function by using the point interpolation based on RBF. Then, subdomains are taken as elements of the Galerkin FEM to approximate the entire solutions. The hybrid approach has been proved as a valid method, and inherited advantages of RBF and FEM. Nevertheless, the shape of subdomain need not be rectangular. More flexible form can be better adapted to electromagnetic problems. Triangular and cubical subdomain will be investigated, respectively. In order to verify the improved method, several numerical examples including 3-D electromagnetic problem will be computed.

ID: 676 / PB5: 14

Track 20

Topics: Numerical Techniques

Keywords: FDTD, Microstrip Antennas, FR-4, UWB.

Numerical Simulation using FDTD Method to Estimate Return Loss for Ultra-Wideband Antennas Built with High Loss FR-4 Substrate

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This work presents an accurate simulation using FDTD-UPML of two microstrip antennas built with FR-4 substrate, being one for validation and the other an ultra-wideband antenna. The FR-4 is inhomogeneous, anisotropic and has high tangent loss which become the project and estimation of radiation characteristics an challenger task. However, the FR-4 is easy to manipulate and is cheaper than others substrates commonly used to manufacture microstrip antennas. To enhance the FDTD code, substrate loss and plane wave excitation were implemented. Besides, Dey-Mitra algorithm was also implemented since it reduces simulation errors in small structures and corners as well as bents and curves. To compare the results simulated, the return loss was used. The microstrip antennas was also simulated in CST Microwave Studio and built. The measurements were performed in a Network Analyzer. The results were satisfactory and slightly higher than those found in literature.

ID: 694 / PB5: 15

Two Pages Short Version

Topics: Numerical Techniques

Keywords: Anisotropic media, finite-element time-domain (FETD), perfectly matched layer (PML)

Uniaxial PML in Spherical and Cylindrical Coordinates for Finite-Element Time-Domain Formulations

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In order to reduce the buffer space around objects in a computational space, application of cylindrical or spherical perfectly matched layer (PML) can be very effective. Despite their wide-spread application in the finite-different time-domain (FDTD) method, we could not find any paper discussing this issue in the context of the finite-element time-domain (FETD) method. In this paper, we develop and implement uniaxial PML (UPML) for both mixed and vector wave equation (VWE) FETD formulations. In contrast to the convolutional-based formulations of the VWE FETD, we adopt the Möbius transformation technique, which is simpler in form and easier-to-implement.

ID: 696 / PB5: 16

Two Pages Short Version

Topics: Numerical Techniques

Keywords: Dispersive media, Finite element time domain method, Graphics processing unit, Parallel processing.

Dispersive Möbius Transform Finite Element Time Domain Method on Graphics Processing Units

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We demonstrate the novel use of graphics processing units (GPUs) in accelerating dispersive finite element time domain (FETD) methods based upon the Möbius (bilinear) z-transform technique. By utilizing the immense computational potential of modern GPUs via NVIDIA's Compute Unified Device Architecture (CUDA) language, we are able to diminish the gap between dispersive FETD methods and their non-dispersive counterparts, facilitating the study of a wider range of physical phenomena. Our analyses indicate that the amount of performance gain achieved is directly related not only to the number of variables, but also to the amount of dispersive material present in the problem, with very large majoritarily dispersive problems seeing the most improvement.

PB6: Novel computational methods for machines and devices 2

Time: Tuesday, 30/Jun/2015: 1:45pm - 3:25pm · Location: Lounge

Session Chair: Nelson Sadowski

Session Chair: Takashi Todaka

ID: 37 / PB6: 1

Track 09

Topics: Electromagnetic Compatibility, Novel Computational Methods for Machines and Devices

Keywords: analytical model, electromagnetic field, equivalent circuits, propagation constant, solid rotor

Magnetic Analysis and Parameters Calculation for Solid-Rotor Induction Motor Coated with Copper Layer

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This paper employs analytical method to analyze electromagnetic field and calculate parameters of solid-rotor induction motor coated with copper layer taking the radial nonlinear magnetic permeability of solid steel and particularity of copper layer into consideration. The 2D electromagnetic field multi-layer model was established. The specific method dealing with parameters determination needed by multi-layer iterative procedure was proposed to calculate the equivalent circuit parameters of solid steel. The propagation coefficient was introduced to calculate parameters of copper layer. A Two-Degree-of-Freedom Direct Drive Induction Motor with solid-rotor coated with copper layer was investigated. The accuracy of analytical method is verified with comparison to finite element method.

ID: 43 / PB6: 2

Track 10

Topics: Novel Computational Methods for Machines and Devices

Keywords: Approximation methods, eddy currents, finite element analysis, proximity effects

Efficient Finite Element Computation of Circulating Currents in Thin Parallel Strands

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Electrical machines often utilize stranded parallel conductors to reduce the skin-effect losses. This practice can lead to uneven total current distribution among the strands, increasing the resistive losses. Direct finite element analysis of circulating current problems can be computationally costly due to the large number of nodal unknowns in the conductor mesh. Methods to reduce the computational burden exist for special problems only. This paper proposes two efficient finite element formulations to solve circulating current problems with arbitrary winding configurations. According to simulations, the proposed methods yield reasonably accurate results significantly faster than the traditional brute-force approach.

ID: 59 / PB6: 3

Track 17

Topics: Novel Computational Methods for Machines and Devices

Keywords: Coupling circuits, Circuit faults, Induction motors

Fault Behavior Calculation of High Efficient Single Phase Induction Machines using 2-D Transient FEM

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The calculation of the fault behavior of highly efficient single phase induction machines by means of the finite-element method necessarily includes a transient process. The different switching states of both windings and the capacitors must be taken into account; for this an electrical circuit is coupled. Faults (separated by time, rotor position and phase angle) are presented and calculated by Finite-element models. The results of different operating strategies of single phase induction machines are compared.

ID: 69 / PB6: 4

Track 12

Topics: Optimization and Design, Novel Computational Methods for Machines and Devices

Keywords: Synchronous generator, magnetic losses, hybrid excitation, finite element analysis

Iron loss evaluation on a hybrid synchronous generator using FEM

Juliana Luisa Muller Iamamura¹, Maxime Ployard^{1,2}, Frédéric Gillon¹, Abdelkader Benabou¹, Daniel Laloy², Aymen Ammar²

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This paper presents a study of iron losses on a 1MVA synchronous hybrid generator. The machine operates as a classical salient pole with wound rotor generator, with permanent magnets on the rotor poles surface. A numerical model of this machine has been developed and used to analyze iron losses with the association of different a posteriori methods. The results are compared to measurements performed on the generator itself. Also, the influence of some geometrical details on the rotor poles has been considered.

ID: 105 / PB6: 5

Track 11

Topics: Novel Computational Methods for Machines and Devices

Keywords: eddy currents, permanent magnets, 2D Finite Element Analysis

Eddy current computation in 2D-FEM for permanent magnet loss calculation

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2D Finite Element Modelling (FEM) of electromagnetic devices, including massive parts with eddy currents, often requires that the total net current through these parts is zero. One commonly studied device incorporating these aspects is the permanent magnet synchronous machine (PMSM) for which the calculation of eddy current losses in the permanent magnets (PM) is of importance when operating at high frequency. The presented work deals with a technique allowing the imposition to zero of the total net current through each of the permanent magnets in a PMSM. Results of the proposed technique in 2D FEM approach are compared with the ones of 3D FEM in terms of eddy current spatial distribution and losses

ID: 125 / PB6: 6

Track 15

Topics: Novel Computational Methods for Machines and Devices

Keywords: AC motors, induction motors, eddy currents, finite element analysis

Modeling end effect due to axial slitting in solid-rotor induction motors

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Axial slits remarkably improve performance of the solid-rotor induction motors due to reduction of the rotor surface impedance. Those also change the end effect, but this is usually ignored in analysis, as it would require taking account for a realistic current density distribution. This work employs a simplified local 3-d finite element analysis to create a surrogate model of this end effect. The latter describes the effective conductivity which reduces the third dimension in the eddy-current problem and enables a more accurate 2-d modeling. Validity of the approach is confirmed experimentally.

ID: 184 / PB6: 7

Track 17

Topics: Novel Computational Methods for Machines and Devices

Keywords: Halbach PM Arrays, equivalent-magnetizing-current (EMC), linear generator, wave energy conversion

Magnet Field Analysis Model to Halbach PM Slotless Linear Generator for Wave Energy Conversion

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Magnetic field analysis model of Halbach PM Arrays is presented based on analytical method and equivalent-magnetizing-current (EMC) in this paper. To reduce the total harmonic distortion (THD) of EMF waveform, a Halbach PM Arrays slotless tubular linear generator for wave energy conversion is proposed and analyzed. Moreover, the generator is assessed by the magnetic field analysis model and finite-element analysis methods (FEM), and constructional details of the generator are proposed for suitable air-gap flux density. The influence of the main design parameters for the slotless generator is investigated, and is compared with those of R-magnetized structure. The analysis results obtained by the model and FEM method confirm the exactness of the proposed generator.

ID: 319 / PB6: 8

Track 17

Topics: Optimization and Design

Keywords: Colenoid, electromagnetic actuator, equivalent circuit, multi polar solenoid

Design of Electromagnetic Linear Actuator by Using the Equivalent Magnetic Circuit Method

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This paper is concerned with the design variations of electromagnetic linear actuator with divided coil excitation system such as colenoid (COL) and multipolar solenoid (MPS) by using the equivalent magnetic circuit (EMC). At first, the magnitude and direction of magnetic flux in each pole can be obtained by using the EMC method. And magnetic flux density of each pole region is calculated by the superposition principle. To make the magnetic flux density uniform in each pole, pole width is adjusted by the iteration method. Comparing with the initial model having equal pole distance, the generated clamping force of optimized model with EMC has increased and almost same force characteristics with the optimization results by the response surface methodology (RSM). Based on the results with EMC method, the characteristics of electromagnetic linear actuator are investigated with the variation of slot width. An electromagnetic linear actuator is developed to produce clamping force of 40kN and the experimental results show that it can be used to hold workpiece firmly instead of the pneumatic cylinder in chucking system.

ID: 355 / PB6: 9

Track 17

Topics: Novel Computational Methods for Machines and Devices

Keywords: HTS magnet, REBCO tape, screening current, superconducting magnet, YBCO-coated conductor.

Simulation of Screening Current Induced in YBCO Pancake Coil by 2D FEM with 3D Magnetic Field Analysis

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The effect of screening current in high temperature superconducting (HTS) double-pancake coil on generated magnetic field is investigated by experiments and numerical simulation all over the world. However, an YBCO tape is too thin to make a mesh in 3D space. Therefore, the common 3D FEM is inapplicable to the simulation of screening current. We try to model 2D finite element mesh into an YBCO tape of HTS coil in 3D space. In this paper, the reduction in the central magnetic field due to screening current-induced magnetic field is simulated by 2D finite element method in 3D space.

ID: 446 / PB6: 10

Track 15

Topics: Multi-physics and Coupled Problems, Novel Computational Methods for Machines and Devices

Keywords: Magnetohydrodynamics, Electromagnetic devices, Actuators

Electric Vector Potential Formulation to Model a Magnetohydrodynamic Inertial Actuator

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A magnetohydrodynamic (MHD) inertial actuator using a liquid metal rather than a solid mass is presented. The liquid, inside an annular channel, is accelerated thanks to transverse electric and magnetic fields. This paper proposes an electric vector potential formulation to compute the angular momentum's device under the assumption that the flow is laminar.

ID: 494 / PB6: 11

Track 09

Topics: Novel Computational Methods for Machines and Devices

Keywords: Finite element analysis, induction motor, inter-bar current, skewed rotor slots

Simplified 3D Modeling for Skewed Rotor Slots with End-ring of Cage Induction Motors

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Highly accurate electromagnetic field analysis is required for the development of high-efficiency electric machines. In order to evaluate the characteristic of induction motors appropriately, it is desirable to consider effects of skewed rotor slots and end-ring in the 3D magnetic field analysis. However, 3D analysis is not easy from the standpoint of calculation costs. In this paper, we propose a novel 3D modeling method for skewed rotor slots with end-ring and clarify its validity in the analysis of cage induction motors with semi-closed rotor slots. Additionally, we perform the inter-bar current analysis of a cage induction motor by using the proposed model combined with the homogenization method to consider laminated iron core with low computational cost.

ID: 601 / PB6: 12

Track 14

Topics: Optimization and Design, Mathematical Modelling and Formulations, Novel Computational Methods for Machines and Devices

Keywords: electric machine, finite element method, genetic algorithm, parameter optimization, wind power.

Design and Optimization of Electric Continuous Variable Transmission System for Wind Power Generation

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A novel brushless electric continuous variable transmission (E-CVT) system is presented as an alternative solution for variable-speed constant-frequency operation of wind turbine application. The E-CVT system consists of two rotors and two stators without gearbox and brushes. The structure and operation principle are introduced and the performance is analyzed. A global optimal design method based on genetic algorithm (GA) and finite element method (FEM) is proposed to optimize the parameters for achieving maximal power density.

ID: 624 / PB6: 13

Track 10

Topics: Static and Quasi-Static Fields, Novel Computational Methods for Machines and Devices

Keywords: Brushless motor, demagnetization, magnetic analysis, switching circuit, permanent magnet motors.

Demagnetization Characteristic Analysis in accordance with Freewheeling Current in BLDC Motor

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In this study, demagnetization characteristic is analyzed according to variation of freewheeling current through the finite-element method in brushless dc motor. Theoretically, the freewheeling current is affected by variations of the rotating speed and load. In order to validate the relation between the demagnetization and the freewheeling current, we analyzed magnetic field distribution depending on change of freewheeling current. As a result, we confirmed that demagnetization gets worse by growing slope of freewheeling current.

ID: 681 / PB6: 14

Track 04

Topics: Static and Quasi-Static Fields, Numerical Techniques, Education, Novel Computational Methods for Machines and Devices

Keywords: Finite element method, model refinement, subproblems, transformers

Subproblem Methodology for Progressive Finite Element Modeling of Transformers

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Model refinements of transformers are performed via a subproblem finite element method. A complete problem is split into subproblems with overlapping meshes, to allow a progressive modeling from ideal to real flux tubes, 1-D to 2-D to 3-D models, linear to nonlinear materials, perfect to real materials, wired to volume inductors, and homogenized to fine models of cores and coils, with any coupling of these changes. Its solution is the sum of the subproblem solutions. The procedure simplifies both meshing and solving processes, and quantifies the gain given by each refinement on both local fields and global quantities. Efficient ways to chain the refinements are proposed and tested.

OA4: Wave propagation

Time: Tuesday, 30/Jun/2015: 3:50pm - 5:30pm · *Location:* Room #0100

Session Chair: Herbert De Gersem

Session Chair: Igor Tsukerman

ID: 139 / OA4: 1

Track 19

Topics: Wave Propagation, Numerical Techniques

Keywords: Wave propagation, Complementary formulation, Adaptive mesh refinement.

Complementary discrete geometric h-field formulation for wave propagation problems

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By discretizing the magnetic field formulation for a wave propagation problem on a pair of dual interlocked grids, we obtain a discrete formulation which is complementary to the electric field formulation discretized on the same grids. In this work, we present how the h-formulation is obtained in the Discrete Geometric Approach framework; then we use it to devise an adaptive refinement scheme. Finally, considerations on the convergence of the discrete h-formulation with respect to the discrete electric field one are discussed.

ID: 166 / OA4: 2

Track 05

Topics: Wave Propagation, Numerical Techniques

Keywords: Periodic problems, layered media, mixed potentials, Green's functions, Ewald method, leaky-wave antennas

Enhanced Convergence of Periodic Potentials in Stratified Media Through Asymptotic Extractions

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The efficient computation of periodic Green's functions is discussed here for an arbitrarily directed array of point sources in layered media. These Green's functions are necessary to formulate boundary integral equations for arrays of scatterers inside a general layered medium, solved with a method of moments approach in the spatial domain. For this reason, mixed-potential Green's functions—having a mild spatial singularity—are selected. The case of horizontally oriented dipoles (i.e., orthogonal to the stratification direction) is rather simple and has been solved previously; asymptotic terms are extracted that correspond to free-space Green's functions of periodic arrays of dipoles. On the other hand, the case of vertically-oriented dipoles (i.e., aligned perpendicular to the layers) is more intricate, since the extracted terms cannot be transformed into well-known Green's functions. A previous work dealt with arrays of line sources, while previous conference papers described the new approach for point sources, without providing analytical details. Applications to the dispersive analyses of leaky-wave antennas, not included here for the sake of brevity, will be presented at the conference.

ID: 522 / OA4: 3

Track 20

Topics: Wave Propagation, Nano-Electromagnetic Computation, Numerical Techniques

Keywords: carbon compounds, computational electromagnetics, finite difference methods, nanomaterials, stochastic processes

A Generalized Domain-Decomposition Stochastic FDTD Technique for Complex Nanomaterial and Graphene Structures

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The systematic and rigorous design of realistic nanocomposite applications and finite graphene setups with arbitrary media uncertainties is presented in this paper via a 3-D covariant/contravariant stochastic finite-difference time-domain method. The novel algorithm employs extra nodes according to a convex combination of all available spatial increments and develops a robust domain-decomposition scheme along with the pertinent Lagrange multipliers to significantly reduce the computational overhead. In this manner, the mean value and standard deviation of field components are calculated in a single run, which is further accelerated through graphics processor units and parallel programming. The profits of the proposed algorithm are certified by various nanoscale components with demanding statistical material variations.

ID: 75 / OA4: 4

Track 05

Topics: Static and Quasi-Static Fields, Numerical Techniques, Bio-Electromagnetic Computation

Keywords: Magnetic stimulation, Uncertainty, Polynomial Chaos Expansion, Model Order Reduction.

Fast MOR-based Approach to Uncertainty Quantification in Transcranial Magnetic Stimulation

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We propose a Model Order Reduction approach to the uncertainty quantification in Transcranial Magnetic Stimulation and compare it with a standard non-intrusive PCE approach. Thanks to the new algorithm the computational time is reduced by more than two orders of magnitude with respect to standard non-intrusive approaches, at comparable accuracy.

ID: 48 / OA4: 5

Track 02

Topics: Static and Quasi-Static Fields, Electromagnetic Compatibility, Numerical Techniques

Keywords: Non-orthogonal partial element equivalent circuit (PEEC) method, filament mutual inductance, numerical integration, partial element computation

New numerical integration routine for the nonorthogonal PEEC approach

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This contribution focuses on special aspects regarding numerical integration routines for nonorthogonal PEEC cells. By using averaged orthogonal subelements in the numerical integration routine, the slow convergence caused by the singularities is avoided and consequently, a fast evaluation of the self terms is enabled. The approach is verified by a spiral planar coil with a wire of circular cross section. Here, the current density is computed by the proposed algorithm and compared with FEM results showing a good agreement.

OA5: Novel computational methods for machines and devices

Time: Wednesday, 01/Jul/2015: 8:30am - 10:10am · Location: Room #0100

Session Chair: Piergiorgio Alotto

Session Chair: Hartmut Brauer

ID: 52 / OA5: 1

Track 12

Topics: Software Methodology, Novel Computational Methods for Machines and Devices

Keywords: Equivalent circuits, finite element analysis, tree graphs

A Systematic Approach for Solving Coupled Reluctance Network and Finite Element Models

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Accuracy of reluctance network models can be improved by coupling them to finite element models. However, actually describing the coupling in terms of a system of equations can be difficult and error-prone, especially with large problems. This paper presents a systematic method to generate the system of equations for a coupled reluctance network and a scalar potential finite element problem. The method works with arbitrary network topologies and can be easily extended to nonlinear problems as well. Validity of the approach is demonstrated on a simple synchronous reluctance machine model.

ID: 126 / OA5: 2

Track 16

Topics: Novel Computational Methods for Machines and Devices

Keywords: Brushless motors, finite element analysis, steady-state analysis

A steady-state field-circuit model based on the magnetostatic analysis for PM-BLDC motors driven from 1200 and 1800 quasi-square wave inverters

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A consistent and computationally efficient finite element model for simulation of the steady-state operation of permanent magnet brushless DC motors driven from quasi-square wave inverters is proposed. The algorithm combines the magnetostatic finite element and the steady-state time-periodic circuit models with time averaging. A weak field-circuit coupling is established through the effective constant current and lumped parameters extracted at various loading conditions. The performance characteristics, determined via the proposed model for the two different motors, are comparable to those obtained from the comprehensive time-stepping finite element model, with the execution time being approximately hundred times shorter for the former.

ID: 622 / OA5: 3

Track 02

Topics: Mathematical Modelling and Formulations, Novel Computational Methods for Machines and Devices

Keywords: Additional winding, finite-element methods, induction machines, numerical models, state space methods, synchronous reluctance motor

Finite Element Circuit Based Modeling for Computing Electromagnetic Forces in Synchronous Reluctance Machine Rotor

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This work demonstrates a novel finite element based modeling for computing the electromagnetic forces in a synchronous reluctance motor with different eccentricities of the rotor. Here, the model interpolates data from a look-up table created in advance by combining a numerical and an analytical approach where the relationship between the stator currents and flux linkages are identified with static finite element analysis. The state-space based model is capable enough like a non-linear time stepping finite element model to predict the electromagnetic forces on the rotor with different sets of uneven magnetic flux density across the airgap, even at much lower computational burden.

ID: 58 / OA5: 4

Track 19

Topics: Mathematical Modelling and Formulations, Numerical Techniques, Novel Computational Methods for Machines and Devices

Keywords: Adaptive algorithms, adaptive mesh refinement, finite element analysis, wavelet transforms.

A Performance Comparison of Adaptive Operator-Customized Wavelet Basis and Adaptive H-refinement Methods for 2-D Finite Element Analysis

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This paper compares the performance of the popular adaptive H-refinement (HR) technique for the Finite Element Method (FEM) with the Operator-Customized Wavelet Basis (OCWB) FEM in its adaptive version. The latter is somehow an evolution of the HR method with the use of second generation wavelet theory, which allows the solution to be decoupled between iterations, decreasing significantly the total number of degrees of freedom and consequently, the processing time. Conversely, this procedure increases the algorithm complexity, that being the reason why there are such few applications on the subject. Like the HR method, adaptive OCWB can be programmed with various strategies. Since the results are shown in terms of processing time on a regular PC, both algorithms have been developed with similar structures.

ID: 78 / OA5: 5

Track 07

Topics: Optimization and Design, Multi-physics and Coupled Problems, Novel Computational Methods for Machines and Devices
Keywords: Pareto optimization, Multi-physics optimization, Induction machine, Finite element analysis

Pareto Optimization in Terms of Electromagnetic and Thermal Characteristics of Air-Cooled Asynchronous Induction Machines Applied in Railway Traction Drives

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In terms of electromagnetic and thermal parameters, the utilization of asynchronous induction machines applied in railway traction drives is much higher than those used in industrial drives. Therefore, the multi-physics optimization with respect to electromagnetic and thermal behaviour is nowadays one of the most important design task with such machines. The paper discusses a novel optimization approach considering the Pareto optimal design to improve both electromagnetic characteristics and thermal behaviour using a sequential coupling of electromagnetic, thermal as well as fluid dynamics analyses.

PC1: Bio-electromagnetic computation

Time: Wednesday, 01/Jul/2015: 10:30am - 12:15pm · *Location:* Cafeteria

Session Chair: Walter Pereira Carpes Jr

Session Chair: Nathan Ida

ID: 35 / PC1: 1

Track 05

Topics: Bio-Electromagnetic Computation

Keywords: Implantable biomedical devices, Finite element analysis, Fast Fourier transforms

Efficient Computation of the Neural Activation during Deep Brain Stimulation for Dispersive Electrical Properties of Brain Tissue

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Deep brain stimulation (DBS) is a widely employed neurosurgical method to treat symptoms of neurodegenerative disorders. Computational modeling of DBS can help to gain insight into the mechanisms of its action. Among these models, the estimation of the volume of tissue activated (VTA) comprises a method to predict the extent of beneficial stimulation and unwanted side effects. This method requires the computation of the time-dependent extracellular potential in the proximity of the stimulation electrode, which is, in general, computationally expensive due to the dispersive electrical properties of brain tissue. We present an adaptive scheme based on two interpolation methods, which approximates the transfer function of the extracellular potential distribution in the frequency-domain. The results suggest that the proposed method is able to substantially reduce the computational expense for the computation of the extracellular field distribution and VTA compared to the standard approach.

ID: 42 / PC1: 2

Track 19

Topics: Static and Quasi-Static Fields, Bio-Electromagnetic Computation

Keywords: Biomedical Computing, Biomedical Engineering, Computational Electromagnetics, Bioimpedance, Finite Element Analysis

Forward Solver in Magnetoacoustic Tomography with Magnetic Induction by Generalized Finite Element Method

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Magnetoacoustic Tomography with Magnetic Induction (MAT-MI) is a hybrid imaging modality proposed to reconstruct the electrical impedance property in biological tissue by integrating magnetic induction and ultrasound measurements with high resolution. One of the major problems of MAT-MI is the singularity problem and its numerical errors caused by singular MAT-MI acoustic sources at conductivity boundaries and interfaces. In order to achieve more computational accuracy especially on the conductivity boundaries and interfaces of inclusions, we have developed a forward solver in MAT-MI to compute the problem with Generalized Finite Element Method (GFEM) in the present study. The novelty of the work relies on the first adaption of GFEM in MAT-MI computation. Using the solver the distribution of the eddy current and the distribution of the acoustic source are computed accurately in the object with computer simulation. The results demonstrate the feasibility of the forward solver in MAT-MI. And it shows that it is capable of achieving good accuracy and stability with GFEM.

ID: 65 / PC1: 3

Track 15

Topics: Bio-Electromagnetic Computation

Keywords: Electric properties tomography, Magnetic resonance imaging, Maxwell equations, Numerical simulation

Comparative Analysis between Different Approaches for Electrical Properties Tomography

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This paper presents a comparative analysis between three numerical methods used in the electrical properties tomography to reconstruct the conductivity and permittivity of biological tissues from the radiofrequency magnetic field map measurable in a magnetic resonance system. The analysis is performed on model problems, whose solution provides the magnetic field values to be used as virtual measurements. The effects on the result accuracy of very high and very low conductivity materials (mimicking the presence of medical implants) are finally evaluated.

ID: 97 / PC1: 4

Track 15

Topics: Bio-Electromagnetic Computation

Keywords: Exposure, magnetic field, spot welding, low frequency

A simplified procedure for the exposure to the magnetic field produced by resistance spot welding guns

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This paper describes a simplified but effective methodology for the assessment of the human exposure to the magnetic field generated by resistance spot welding guns. The procedure makes possible to compute the induced electric field in time domain as required by the standardized methodology for the assessment of pulsed magnetic fields (i.e. the weighted peak method). In this paper we prove that the proposed procedure provides results in accordance with a rigorous approach allowing a huge reduction of the computation burden and, consequently, a significant speedup.

ID: 118 / PC1: 5

Track 14

Topics: Optimization and Design, Numerical Techniques, Bio-Electromagnetic Computation

Keywords: Artificial Neural Network, Electrical Capacitance Tomography, Finite Element Method, Inverse Problems, Particle Swarm Optimization.

Nonlinear Electrical Impedance Tomography reconstruction using Artificial Neural Networks and Particle Swarm Optimization

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Recent medical imaging technologies, such as Electrical Impedance Tomography (EIT), offer the advantages of being noninvasive and it do not generate ionizing radiation. The main difficulty in applying EIT is to solve a very ill-posed nonlinear inverse problem. Given a set of electrical voltages measured at the boundary of a finite elements model, the goal is to identify the materials present in the domain by determining their electrical conductivities. However, since EIT is a nonlinear problem, various algorithms proposed in the literature can only approximate real conductivity distribution. Nonlinear algorithms, especially Artificial Neural Networks (ANN), have been proposed to solve this inverse problem, but these algorithms are usually limited by slow convergence issues during the training phase of an ANN. In this paper, the Particle Swarm Optimization method (PSO) is used to train an ANN to solve the EIT problem. A PSO algorithm is an Evolutionary Algorithm (EA) which has recently been used to train ANN. It has been proven that, compared to the classical Back-Propagation (BP) algorithm, PSO is capable of generating both faster and higher convergence. In addition, this paper also shows that the proposed method is capable of dealing with noisy data and imperfections in the Finite Element (FE) discretization, an important source of errors in EIT imaging.

ID: 121 / PC1: 6

Track 13

Topics: Mathematical Modelling and Formulations, Numerical Techniques, Bio-Electromagnetic Computation

Keywords: Artificial Neural Networks, Complexity, Electrical Capacitance Tomography, Inverse Problems, Finite Element Method

Divide and Conquer Neural Networks for Two-Dimensional and Three-Dimensional Electrical Impedance Tomography

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Electrical Impedance Tomography (EIT) is a relatively modern approach for imaging applications, and is a promising technology for biomedical applications. By applying an electrical current to a living tissue and measuring the electrical potential at different points of the boundary of the tissue, it is possible to solve the inverse problem and allow us to generate a map of the conductivities of the tissue. However, since this is an ill-posed problem, solving a non-linear EIT problem is usually done by linear inverse solvers in order to regularize and reduce the ill-posedness of the problem. Recently, use of Artificial Neural Network (ANN) to solve an EIT inverse problem has been proposed. ANNs are capable of non-linear approximations, and can give a nonlinear conductivity distribution. Although several works have been published on 2-dimensional FE models, very little work has considered three-dimensional problems. In this paper, a solution based on Divide and Conquer and ANNs is used to solve the non-linear inverse problem without any linearization. The solution presented here aims to reduce the difficulty of training a large ANN, which is commonly required to solve a 3D-EIT problem with Artificial Intelligence (AI) algorithms.

ID: 197 / PC1: 7

Track 12

Topics: Static and Quasi-Static Fields, Mathematical Modelling and Formulations, Bio-Electromagnetic Computation

Keywords: Electrical stimulation, Implantable biomedical devices, Bioimpedance, Numerical simulation, Optimization

Investigation of the Electric Field Distribution within an Electrostimulated Microstructure of Cancellous Bone

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Electrostimulative fields are used to accelerate bone regeneration after fractures and to treat bone diseases. Most of these systems have upper and lower thresholds for electromagnetic fields which have proven to have a positive effect towards bone growth. The biomechanical background, however, is still subject of ongoing research. Using numerical simulation, this paper investigates the field distribution within the microstructure of cancellous bone, which is often regarded as homogenous structure. Basing on microscopic computer tomography a small sample of cancellous bone is separated in cortical bone and red bone marrow. The field distributions, which result from a specially implemented voltage source, suggest that bone generating cells are exposed to higher electric fields than expected.

ID: 341 / PC1: 8

Track 10

Topics: Bio-Electromagnetic Computation, Multi-physics and Coupled Problems

Keywords: Electromagnetic induction, finite element analysis, fuzzy neural networks, prediction methods

Real-Time Prediction of Temperature for Electromagnetic Heating Therapy in Deep-Seated Tissue

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his paper aims to develop a model for predicting the temperature response of tissues in the electromagnetic heating therapy (EHT) when using a magnetic flux concentrator to improve the heating efficiency. Since the EHT has two critical challenges when applied to deep-seated tissue heating: 1) the temperature could not be accurately measured and 2) the magnetic field intensity would decrease with increasing depth. Finite element method (FEM) is suitable for the coupled analysis with electromagnetic fields and heat transfer, it could be used to predict the temperature profiles in deep tissue implanted by magnetic materials. An adaptive network fuzzy inference system (ANFIS) model is further implemented based on the simulated data generated by FEM model. The real-time data acquisition of time and depth would be able to predict the maximum temperature of tissues by ANFIS model in the treatment process. The experimental results show the remarkable consistency between ANFIS and FEM at different depths. Compared with the porcine liver in vitro experiment, the two temperature prediction models indicate favorable prediction capability.

ID: 358 / PC1: 9

Track 16

Topics: Mathematical Modelling and Formulations, Numerical Techniques, Bio-Electromagnetic Computation, Electromagnetic Sensors, Sensing and Metrology

Keywords: finite elements (FEM), finite integration technique (FIT), Guide to the expression of Uncertainty in Measurements (GUM), uncertainty quantification

Fast uncertainty quantification of fields and global quantities

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We introduce a technique for uncertainty quantification of fields and global quantities based on the Guide to the expression of Uncertainty in Measurements (GUM). It is much faster than alternative approaches based on Monte Carlo or polynomial chaos expansion while maintaining good accuracy when the materials uncertainty is moderate. The method is applied to electro-quasistatic (EQS) problems arising in biomedical engineering. A good agreement is found with respect to the Monte Carlo method.

ID: 400 / PC1: 10

Track 19

Topics: Wave Propagation, Numerical Techniques, Bio-Electromagnetic Computation

Keywords: Full-wave electromagnetic analysis, Finite element method, Numerical human model, Mesh smoothing

High-accuracy electromagnetic field simulation using numerical human body models

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In this study, a high-accuracy analysis for the electromagnetic field based on the finite element method using numerical human body models is investigated. In this paper, we propose a mesh smoothing technique for reduction of noise caused by reflection and scattering of the electric fields in boundaries between different materials in the human body models.

ID: 424 / PC1: 11

Track 12

Topics: Bio-Electromagnetic Computation

Keywords: Computational biophysics, finite element analysis, cochlear implants, computational modeling, numerical simulation

Electrical Stimulation of Spiral Ganglion Cells in the Human Cochlea: A 3D Model

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Electrical stimulation of auditory nerve fibers by cochlear implant electrodes has been an approved clinical practice to restore the hearing sensation in profoundly deaf people. Profound deafness is largely attributed to the loss of haircells and subsequent decay of peripheral processes of auditory nerve fibers in the cochlea. In such pathological condition, spiral ganglion cells (SGN) which are intact with central process of auditory nerve fibers in Rosenthal's canal play a crucial role to generate and propagate the action potentials in response to the applied electric field. In this paper we describe the SGN response to the applied electric field by a bipolar electrode. Unlike the other existing models, we have considered the geometry of SGN and cochlea with essential approximations to discuss the signal propagation through the SGN at basal region of the cochlea via appropriate visualizations. This kind of a detailed 3D model serves as a useful tool to have a deeper understanding about the functionality of cochlear implant electrodes.

ID: 431 / PC1: 12

Track 11

Topics: Bio-Electromagnetic Computation

Keywords: Finite-element method, Magnetic field effects, Medical treatment, Modeling, Transcranial magnetic stimulation

Evaluation of the Electric Field Induced in Transcranial Magnetic Stimulation Operators

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This work aims at investigating the exposure experienced by the nursing staff executing transcranial magnetic stimulations (TMS). The analysis is carried out through the finite element method, using the Duke (Virtual Family) anatomical model to represent the operator body. The TMS apparatus is a spiral circular coil with axis parallel to the body axis supplied by a short duration sinusoidal current. The electromagnetic field problem is formulated in terms of vector and scalar potentials. The results show that the operator exposure exceeds the basic restrictions, suggested by the Guidelines of the International Commission On Non-Ionizing Radiation Protection, when the distance from the coil decreases below safe limits, so requiring in that case the use of shielding systems.

ID: 616 / PC1: 13

Track 11

Topics: Bio-Electromagnetic Computation, Material Modelling

Keywords: biomedical electrodes, brain stimulation, electrical stimulation, finite element analysis

Modeling Deep Brain Stimulation Electrode Interfaces

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Deep brain stimulation is an effective treatment of Parkinson's disease and essential tremor. It involves electrical stimulation of the deep brain area through an implantable electrode. In previous studies, deep brain stimulation electrode-tissue interface was modeled by non-faradaic charge transfer. The electrode was represented by a double layer capacitance only, when faradaic reaction was neglected.

In this paper, a novel electrode-tissue interface, which incorporates the equivalent circuit for faradaic reaction, was incorporated into a finite element model of deep brain stimulation. A finite element model of deep brain stimulation was used to compute the stimulation

region or the volume of tissue activated. Finally, an equivalent circuit model of the electrode/tissue interface was created to validate the finite element modeling result.

ID: 639 / PC1: 14

Track 18

Topics: Bio-Electromagnetic Computation

Keywords: finite element method, sensitivity analysis, regression analysis, transcranial current stimulation

Sensitivity of Transcranial Electric Stimulation to Tissue Conductivities Using Non-intrusive Polynomial Chaos Expansion

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Predictions of effects from transcranial electric stimulations rely on simulations with computer models and therefore quantitatively depend on conductivity definition. We aimed to analyze the sensitivity of the induced current density distribution on conductivity variations by means of a generalized polynomial chaos expansion approach. Non-intrusive simulations were performed in a realistic three compartment finite element method model. The polynomial chaos coefficients were calculated by a regression approach with total order expansion. The results demonstrate highest differences in the current density distribution for variations of the skull and soft tissue conductivities at the edge and underneath the stimulation electrodes. The computed sensitivity of the current density distribution to uncertainties in the choice of conductivity values allows for a safer prognosis of the effect of transcranial electric stimulation.

ID: 641 / PC1: 15

Track 06

Topics: Bio-Electromagnetic Computation

Keywords: Ultrasonic imaging, Bioimpedance, Biomedical imaging, Computational electromagnetics, Computational modeling

The Effect of Electrical Anisotropy and Acoustic Inhomogeneous in Magnetoacoustic Tomography with Magnetic Induction

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Magnetoacoustic tomography with magnetic induction (MAT-MI) is a noninvasive technology for imaging the distribution of electrical impedance in biological tissue. In the sameple, a time-varying magnetic field induces currents. A static magnetic field interact with the currents to produce a Lorentz force. Consequently, the sample will emit ultrasonic waves by the Lorentz force. Some biological materials, such as bone and skeletal muscle, are distinctly anisotropic. And the tissue in most parts of human body, has heterogeneous acoustic properties, which leads to potential distortion and blurring of small buried objects in the impedance images. The objective of this academic communication is to expound the effect of both electrical anisotropy and acoustic inhomogeneous in MAT-MI.

ID: 684 / PC1: 16

Track 02

Topics: Bio-Electromagnetic Computation

Keywords: Electromagnetic fields, human eye, SAR calculation, temperature distribution

Calculation of the SAR and Temperature Rise in the Human Eye due to RF Sources

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This paper presents a thorough numerical analysis of the specific absorption rate (SAR) and temperature increase in a three dimensional (3D) anatomical human eye model exposed to electromagnetic fields (EM) at 1.9GHz, 2.4GHz and 5.1GHz, in particular devices such as tablets, smart phones, etc., situated at 30cm, 15cm and 2cm from the eye. A new 3D model of the human eye composed of nine different tissues with a resolution of 0.5mm is discussed, including a precise definition of the cornea and lens. The thermal problem is solved from the bioheat (Pennes') equation coupling the SAR as an input of the power dissipated by the EM field. Measured values of the irradiated power of the devices were considered for the source of the EM. In terms of maximum temperature, for the source distance of 30cm, the highest values encountered are 0.01C in the cornea, aqueous humor and lens at 5.1GHz. For the source distance of 15cm, the worst case is 0.04C increase in the vitreous humor at 1.9GHz. For the source distance of 2cm, the worst case is 1,62C rise in the lens at 1.9GHz.

PC2: Multi-physics and coupled problems 1

Time: Wednesday, 01/Jul/2015: 10:30am - 12:15pm · Location: Lounge

Session Chair: Lionel Pichon

Session Chair: Maurizio Repetto

ID: 25 / PC2: 1

Track 18

Topics: Optimization and Design, Numerical Techniques, Multi-physics and Coupled Problems

Keywords: Condition monitoring, Degradation, Finite element analysis, Friction, Plug-in connector

Multi-physics Calculation and Contact Degradation Mechanism Evolution of GIB Connector Under Daily Cyclic Loading

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A 3D electromagnetic-thermal-mechanical coupling FEM model of gas insulated bus(GIB) connector is proposed in this paper with special attention on the contact degradation mechanism under normal operation conditions which can be important in the condition monitoring of this equipment. The current constriction effect and contact resistance are taken into account by modeling an equivalent contact bridge between the contact interfaces, and varying of friction coefficient is also considered. Power loss which derived from electromagnetic field calculation is used as load inputs in thermal field analysis. The validity of calculation model is demonstrated by temperature rise experiment and the influence of daily changing of the current and the environmental temperature on thermal and mechanical characteristics of plug-in connector has been analyzed using calculation model. Analysis results show that daily change of current and environmental temperature can make relative motion between conductor and plug-in connector, and the insert depth of connector can be changed under the action of alternating thermal loading which induced by daily change of current and environmental temperature, leading the connector degradation and overheating fault may be induced.

ID: 32 / PC2: 2

Track 10

Topics: Numerical Techniques, Multi-physics and Coupled Problems

Keywords: Coupled field, FEM, Insert depth, Plug-in connector, Short circuit

Temperature and Electromagnetic Force Analysis of GIB Plug-in Connector with Different Insert Depth under Short Circuit Fault

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Electrical dynamic stability and thermal stability are essential for plug-in connector which used in gas insulated bus(GIB), however the insert depth of connector can be changed under the effect of daily cycling loads such as operating current and environment temperature which cause contact degeneration. In order to provide an effective condition monitoring of plug-in connector, A multi-physics coupling FEM model has been developed. The spring preloading contact force and contact bridge radius can be obtained by mechanical analysis with different insert depth. Power loss and electromagnetic force get from electromagnetic field analysis are used as load inputs in thermal-mechanical coupling analysis. Temperature and force characteristics of plug-in connector with different insert depth under short circuit fault are calculated. The results show that with decreasing of connector insert depth, the temperature rise of connector becomes larger. The electromagnetic repulsion force of contact finger is increasing whereas the preload contact force is decreasing, and serious contact failure can be induced with small contact force.

ID: 108 / PC2: 3

Track 15

Topics: Multi-physics and Coupled Problems

Keywords: Computational modeling, Coupled analysis, Macromodels, Model order reduction, MEMS Switches

Combined Multiphysics and RF Macromodels for Electrostatic Actuated Micro-Electro-Mechanical Switches

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Micro-electro-mechanical switches are devices based on micromachining technologies, used to allow or block the propagation of radio-frequency (RF) signals in various applications. Their transition from one RF state to the other involves combined field analysis such as structural, electrostatic (in the case of an electrostatic actuation), squeeze-film damping phenomena. This contribution refers to a methodology to extract a macromodel that includes both the multiphysics behavior and the RF behavior of an electrostatically actuated switch. The extraction is based on the results obtained from various simulations carried of device-level models, with finite element method (for the multiphysics part) or finite integration technique (for the RF part). The novelty with respect to our previous work is that now damping phenomena is included, the macromodel being able to extract not only S-parameters for the RF stable states and static pull-in voltage, but also dynamic pull-in voltage, switching time and pull-out voltage.

ID: 115 / PC2: 4

Track 20

Topics: Numerical Techniques, Multi-physics and Coupled Problems

Keywords: Least squares approximations, Magnetohydrodynamics, Electromagnetic levitation, Meshless method

Validation of Meshless Method based on Weighted Least Square Method for Simulating Electromagnetic Levitation

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Electromagnetic levitation is a kind of magnetohydrodynamic phenomena which is used for measuring the thermo-physical properties of pure metals under high temperature. However, this phenomenon is complicated and detailed mechanisms of this phenomenon have

not been clarified yet. This study proposes the meshless method based on weighted least square method for the analysis of electromagnetic levitation. In this study, the fluid motion equation and the magnetic field equation are coupled by this method. The effectiveness of this method is verified through the analysis of the molten metal behavior.

ID: 136 / PC2: 5

Track 17

Topics: Material Modelling, Multi-physics and Coupled Problems

Keywords: Finite element analysis, magnetic field induced strain, magneto-elasticity, magneto-mechanical effects, magnetostriction

Coupled Magneto-Mechanical Analysis of Iron Sheets Under Biaxial Stress

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A directly coupled magneto-mechanical model is used to analyse the coupled behavior of iron sheets under biaxial magneto-mechanical loading applied by a novel biaxial single sheet tester device. Magneto-mechanically coupled constitutive equations of the material derived using an energy based approach are integrated into a finite element model of the single sheet tester device and simulations are performed to solve for the displacement fields and the magnetic vector potentials in the material. The obtained magnetostrictive strain curves of the studied material under different magneto-mechanical loadings are presented.

ID: 193 / PC2: 6

Track 11

Topics: Multi-physics and Coupled Problems

Keywords: Waveform relaxation method, multirate system, finite element method.

Multirate coupling of controlled rectifier and non-linear finite element model based on Waveform Relaxation Method

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To study a multirate system, each subsystem can be solved by a dedicated software with respect to the physical problem and the time constant. Then, the problem is the coupling of the solutions of the subsystems. The Waveform Relaxation Method (WRM) seems to be an interesting solution for the coupling but it has been mainly applied on academic examples. In this communication, the WRM method has been applied to perform the coupling of a controlled rectifier and a transformer modeled by a non-linear finite element model.

ID: 222 / PC2: 7

Track 02

Topics: Multi-physics and Coupled Problems

Keywords: Conductive particle charging, particle motion, surface charge density, electromagnetic force, numerical analysis

Numerical Analysis and Experiment of Floating Conductor Motion due to Contact Charging in High Voltage System

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In this paper, the motion of conductive particles is modeled and analyzed with a coupled equation. A neutral conductive particle obtains charge when it contacts an electrode. The forces acting on a particle consist of electric, drag and gravitational force. When the electric force is dominant over the other forces, a particle lifts up toward upper electrode. The electric force on a particle is calculated using surface charge distribution, which is analyzed using the finite element method. The dominant forces on the particles are used for driving force in Newton's motional equation to analyze a particle motion. The analysis results show that the total charge, which enables the particle to lift off, is calculated using the coupled equation with respect to the applied voltage. The experiment using a spherical conductive particle is conducted, and the experiment result is compared with the numerical one to validate the numerical method.

ID: 232 / PC2: 8

Track 17

Topics: Multi-physics and Coupled Problems

Keywords: Electromagnetic fields, Electromagnetic coupling, Vibration, Mechanical energy, Permanent magnet machines

Analysis and Tests of Electromagnetic Vibration of a Motor Core Including Magnetostriction under Different Rotation Speed

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This paper presents a generalized magneto-elastic 3D finite element model, which can be used to numerical calculate the magnetic field and structural vibration of laminated cores including magnetostrictive effect. Magnetostriction is a property of electrical steel and is an important cause next to electromagnetism forces of the vibration for motor cores. Implement the model, the vibration of a permanent magnetic synchronous motor core is analyzed and measured under different rotation speed. The analysis results show that the vibration due to magnetostriction is significant and the magnitude of vibration is related with the operating speed, which is agreement with the measurement results.

ID: 282 / PC2: 9

Track 12

Topics: Numerical Techniques, Multi-physics and Coupled Problems

Keywords: Thermonuclear Fusion, Error Fields, Numerical Methods.

Error Field Impact on Plasma Boundary in ITER Scenarios

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Discrepancies in magnetic field maps produced by confinement coils in thermonuclear fusion reactors may drive plasma to loss of stability, and must be carefully controlled during the whole time evolution of each shot using suitable correction coils. Anyway, even when kept below safety thresholds, error fields may alter the geometry of magnetic flux lines, defining the plasma geometry. The present paper, using high accuracy 3D magnetic field computations for confinement coils, addresses the issue of evaluating the effect of

error fields on the plasma boundary shape during the shot, modeled as a sequence of equilibrium configurations. In particular, a procedure able to compute the shape perturbations due to given deformations of the coils has been set up and used to carry out an analysis of relationship between the error field and shape perturbations during the time evolution of ITER programmed scenario.

ID: 315 / PC2: 10

Track 10

Topics: Material Modelling, Multi-physics and Coupled Problems

Keywords: Particle method, Finite element method, Magnetorheological Elastomer, Magnetic forces

Analysis of variable stiffness Magnetorheological Elastomer Employing Particle Method and FEM

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Magnetorheological elastomers (MREs) are composed of silicone and iron powder so that they can possess ferromagnetic and viscoelastic properties. The shape and the stiffness of the MREs change depending on the magnetic field [1]. Therefore, it is expected to be used for an artificial muscle or damping material [2] [3]. However, it is difficult to design because ferromagnetic and viscoelastic properties greatly change depending on ratio of the iron powder and strength of magnetic field. This paper presents a numerical method for MREs analysis by coupling a particle method with a finite element method (FEM), in which the nonlinearity of MREs as Young's modulus, Poisson's ratio is taken into account. The numerical algorithm is described and calculated results are shown.

ID: 445 / PC2: 11

Track 19

Topics: Multi-physics and Coupled Problems

Keywords: Electromagnetic fields, Finite element analysis, Fluid dynamics, Numerical analysis, Temperature

Non-Matching Meshes Mapping Method between Different Finite-Element Models in Magnetic-Thermal Simulations

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In the coupled electromagnetic fluid-dynamical and thermal simulations which are done by weak coupling FEM for the electromagnetic devices, as thermal loads energy losses obtained from electromagnetic calculations are transferred between meshes to calculate the temperature distributions by considering the influence of fluid flow. Because the requirements of meshes discretization scheme are quite different between electromagnetic and fluid-thermal fields, the same finite element model is applied to analyze as possible as to meet the both requirements. It will lead to increase the number of meshes and the time of calculation. However, if the different finite element models are used, the data cannot be directly transferred between corresponding meshes. In this paper, a non-matching mesh mapping method is proposed. The energy losses can be transferred between the different meshes by Gauss integral and coordinate transformation. Moreover, the strategy of precision control and error correction coefficient is proposed to ensure calculation accuracy. This method is applied to an air insulation bus duct system in a literature, the calculation results are compared with the normal same meshes mapping method and experiment results. It provides the validity of the non-matching meshes mapping method.

ID: 538 / PC2: 12

Track 19

Topics: Wave Propagation, Multi-physics and Coupled Problems

Keywords: gas insulated switchgear, very fast transient overvoltage, combined with electromagnetic field and transmission lines, finite difference time domain, modeling and calculating.

A Method of Finite Difference Time Domain Combined with Electromagnetic Field and Transmission Lines

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Transmission structures of gas insulated switchgear (GIS) were mainly composed of uniform transmission line structures and three-dimensional non-transmission line structures, in order to accurately and efficiently calculating very fast transient overvoltage (VFTO) generated by switch operation in GIS, this paper presented a method of finite difference time domain combined with electromagnetic field and transmission lines (3D-1D FDTD), three-dimensional electromagnetic field computation with finite difference time domain method and uniform transmission line computation with finite difference time domain method were respectively used to modeling and time-domain calculation of three-dimensional non-transmission line structures and uniform transmission line structures in GIS. In this paper, coupled boundary conditions connected with electromagnetic field and transmission lines, and stability conditions of iterative calculation were discussed, a long straight busbar in GIS as an example, transient voltages and transient currents at different locations were calculated by 3D-1D FDTD and one-dimensional transmission line equivalent circuit model, both calculation results were contrasted to verify the effectiveness of 3D-1D FDTD.

ID: 81 / PC2: 13

Track 14

Topics: Multi-physics and Coupled Problems

Keywords: magnetoelectric composite, finite element formulation

Mutliphysics Modeling of Thin Layer Magnetoelectric Laminate Composites Using Shell Element

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This paper proposes to use the shell element to model the thin magnetostrictive layers in finite element multiphysics modeling of magnetoelectric laminate composites. The multiphysics model includes the non-linearity of the thin layer magnetostrictive material and the electrical load effects of the ME device. The simulation results of a ME trilayer composite Metglas/PMN-PT/Metglas show the efficiency of the proposed method. This study provides the basis to study the ME devices composed of laminated thin layers.

PC3: Novel computational methods for machines and devices 3

Time: Wednesday, 01/Jul/2015: 10:30am - 12:15pm · Location: Lounge

Session Chair: Laurent Krähenbühl

Session Chair: Jianguo (Joe) Zhu

ID: 71 / PC3: 1

Track 02

Topics: Novel Computational Methods for Machines and Devices

Keywords: Hybrid excitation, laminated frame, leakage flux, measurement and numerical analysis, stray-field loss.

Stray-Field Loss Modeling under Hybrid Excitation in Smoothing Reactors

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The smoothing reactor in HVDC systems uses a DC-AC excitation with multiple harmonics. This paper investigates effective and practical approaches that can be used to confidently determine the stray-field losses under DC-AC hybrid excitations. The proposals presented in the paper are validated using on a well-established smoothing reactor model.

ID: 149 / PC3: 2

Track 05

Topics: Novel Computational Methods for Machines and Devices

Keywords: Distributed computing, Finite element analysis (FEA), magnetic equivalent circuit, Superconducting wind turbine generator, Superconducting coils

A Distributed Equivalent Magnetic Circuit Approach for 10-MW-Class Superconducting Wind Turbine Generators with MgB₂

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This paper proposes an effective design and analysis tool integrating the equivalent magnetic circuit model into distributed magnetic computation technique for the superconducting wind turbine generators considering electromagnetic coupling spatial structure, nonlinear magnetic material, superconducting coils properties, and etc. these exist two most common ways for design and analysis of electrical machines. One is the magnetic equivalent circuit which is used at the initial design stage without considering the dimension size and resulting in the gross electrical parameters of electrical machine. The other is the FEM which is utilized in most cases but is time-consuming and regenerated on the condition of any alterable structure. A distributed computing technique based on magnetic equivalent circuit is divided into three sub models: the first is stator magnetic computing part with nonlinear magnetic material and copper winding; the second is rotor part with superconducting coils and linear non-magnetic material; the third is interface including pole-teeth coupling and air gap. Besides, the 10-MW-class superconducting wind turbine generator, whose rotor adopts MgB₂ superconducting coils and Al alloy pole, while whose stator employs silicon steel sheets and cooper windings, is designed via the distributed equivalent magnetic circuit approach and then verified with FEA. The comparisons validate the effectiveness of the proposed model.

ID: 156 / PC3: 3

Track 17

Topics: Optimization and Design, Novel Computational Methods for Machines and Devices

Keywords: Finite Element Method (FEM), Interior Permanent Magnet Synchronous Generator (IPMSG), Electric Power Generating System (EPGS), Range Extended Electric Vehicle (RE-EV), Optimal Operating Line (OOL).

Adaptive Design and Validation of IPMSG for Superior EPGS of RE-EV compatible to Main Operating Range with Optimal Operating Line

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Numerical design and validation combined with Finite Element Method (FEM) has been performed for realizing the adaptive efficiency distribution and expanded continuous rated power of Interior Permanent Magnet Synchronous Generator (IPMSG) with a built in engine compatible to the mainly frequent operating range for Electric Power Generating System (EPGS) of Range Extended Electric Vehicle (RE-EV). Particularly, the target operating region of IPMSG is specified with Optimal Operating Line (OOL) of the newly developed two cylinders engine. The dominant electromagnetic losses throughout the whole operating region of IPMSG are numerically identified in association with FEM and employed as design target to minimize. In addition, the compact IPMSG is modeled with taken into the advanced cooling structure and MTPA (Maximum Torque Per Ampere) control strategy. Furthermore, the purposely designed prototype is experimentally validated via the resultant efficiency map built-up by the static and dynamic dynamometer tests.

ID: 188 / PC3: 4

Track 14

Topics: Optimization and Design, Novel Computational Methods for Machines and Devices

Keywords: Permanent magnet machines, Rotating machines, Magnetic gear, Finite element analysis, Design optimization

Torque Characteristic Analysis of an Axial-gap-type Magnetic Gear developed as a Speed-up-gear

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This paper presents cogging torque reduction methods for an axial-gap magnetic gear utilizing combination of the number of poles with the stationary pole pieces and modification of the pole piece shape. The axial-gap magnetic gears have larger cogging torque in comparison with the radial-gap type. There are many methods to reduce cogging torque; however the average torque also decreased due to the applied techniques. The large transmission torque gear was developed and demonstrated experimentally. Application of this gear is a speed up gear for micro hydroelectric generation and it will be connected directly with a generator and a waterwheel in water.

Because the installation space (length and outer diameter) is restricted, we have employed an axial gap type in this study. The torque characteristics are numerically analyzed with the three-dimensional finite element method and results are conformed experimentally.

ID: 296 / PC3: 5

Track 19

Topics: Novel Computational Methods for Machines and Devices

Keywords: transformers, coils, numerical simulation, electromagnetic transients

Transformer Windings' RLC Parameters Calculation and Lightning Impulse Voltage Distribution Simulation

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This paper presents a numerical method for calculating the resistance, inductance and capacitance matrices of transformer windings. Importance of their precise calculation is shown in the simulation of voltage distribution over the windings for lightning-impulse test. The results obtained in frequency domain analysis are in a good agreement with the measurement data. All the parameters are calculated using the self-developed solvers, the theory and novelty of which are described in this paper. The presented approach allows fast and accurate high-frequency modeling of transformer windings.

ID: 320 / PC3: 6

Track 07

Topics: Optimization and Design

Keywords: Topology optimization, finite difference time domain, magnetic resonator

Topology Optimization of a Magnetic Resonator Using Finite Difference Time Domain Method for Wireless Energy Transfer

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In this paper, a magnetic resonator is optimized based on electromagnetic wave analysis. To analyze the magnetic resonator, finite difference time domain (FDTD) method is used with Gaussian pulse source and perfectly matched layers. Topology optimization of a magnetic resonator is conducted for maximizing magnetic energy. After those approaches, the fast Fourier transform (FFT) is used to obtain the response of the magnetic resonator system over wide range of frequencies.

ID: 362 / PC3: 7

Track 15

Topics: Numerical Techniques, Novel Computational Methods for Machines and Devices

Keywords: finite element analysis, eddy currents, litz wire, model reduction, switched reluctance machine

2D Modeling of Litz Wires Reduced Model and its Application for Switched Reluctance Machine

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The strong correlation between the level of eddy current losses and the winding geometry shows all the necessity of special attention to the manner of disposition of coils in machine slots and to the wire type whether it's solid or stranded conductor. Since the transposition of winding strands is a recommended solution to reduce eddy current losses, this article suggests an electromagnetic analysis of complex stranded conductors such as litz wires. It is based on a 2D finite element model. A model reduction is also proposed. It allows benefiting from only one complete finite element solution to find fast solutions in the slots domains when any variation of

geometrical or physical data occurred. It allows different problem adapted meshes. Seeing that it prevents the Newton-Raphson iterations, the reduction model presents clear interests in repetitive analysis such as winding optimization processes.

ID: 370 / PC3: 8

Track 06

Topics: Static and Quasi-Static Fields, Numerical Techniques

Keywords: electric motor, finite element analysis, magnetic cores, magnetic flux density

Finite Element Analysis of Local Flux Density Variation in the Synchronous Motor for Core Loss Estimation Considering Current Harmonics

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This research deals with how to analyze flux density changes within the iron core, to predict core loss when operating 3phase permanent magnet synchronous motor by PWM sine wave. When creating sinusoidal current by PWM, large amount of harmonics is mixed in the current; which requires a significant amount of time for analysis. This research suggests a method to calculate flux density changes from each element in a short time, using non-linear FEA and linear FEA concurrently, based on 2-D magneto static FEA.

ID: 407 / PC3: 9

Track 01

Topics: Optimization and Design

Keywords: Finite element method, level set function, regularization, topology optimization

Extension of Topology Optimization Method Based on Regularized Level Set Function to Solving 3-D Electromagnetic Field System

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The topology optimization (TO) method is one of effective tools for practical design of electrical machines. TO could be conventionally achieved using the material density which is allocated in finite elements of design domain. However, material-density-based TO may possibly produce the problematic solutions; e.g. many gray scale area, unfeasible shape, and so on. On the other hand, TO based on the advection of level set function has the superiority from the viewpoint of both continuity and practicability of the optimized solution. In this paper, TO method for solving 3-D magnetic field problem with magnetic nonlinearity is proposed. The validity of proposed method is verified by solving the 3-D magnetic circuit problem.

ID: 492 / PC3: 10

Track 17

Topics: Optimization and Design, Mathematical Modelling and Formulations, Material Modelling

Keywords: Electric vehicles, inductive power transmission, electromagnetic coupling, frequency-domain analysis, air gap

Compensation Considerations for Bidirectional Inductive Charging Systems of Electric Vehicles with Coil Positioning Flexibility

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Bidirectional inductive power transfer systems enable power transfer between stationary electricity source and movable consumers in each direction through electromagnetic coupling. Due to its complexity, a mathematical model is required to design and to control these systems. This paper presents the mathematical analysis and frequency domain analysis for two different compensated (series-series and parallel-parallel) bidirectional inductive power transfer systems. The paper contains the modeling procedure of bidirectional inductive power transfer system's coils in the frequency domain. The prediction of its equivalent circuit values, magnetic stray field values and coil positioning tolerance are determined as well using the JMAG field simulation software. Furthermore, the transmission characteristics and the efficiency of the two compensation topologies are discussed.

ID: 499 / PC3: 11

Track 11

Topics: Mathematical Modelling and Formulations, Numerical Techniques

Keywords: Computational electromagnetics, Grounding, Lightning protection

Novel Formulation to Determine the Potential on the Soil Surface Generated by a Lightning Surge

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This paper presents the development of an analytical formulation for estimating the potential in the soil surface, caused by electric current calculated on a grounding conductor through the Transmission Line Modeling Method (TLM). The formulation has great significance in its use in conjunction with one-dimensional numerical methods in general manner, which are not able to determine such potentials directly. The proposed study is focused on lightning surges and it takes into account the frequency dependence of the soil properties.

ID: 544 / PC3: 12

Track 08

Topics: Novel Computational Methods for Machines and Devices

Keywords: microelectromechanical systems (MEMS) micromotor, magnetic equivalent circuit (MEC), leakage flux, finite element analysis (FEA)

A 3-D Magnetic Equivalent Circuit of an Axial-Flux MEMS Micromotor with Dimension Minimization Analysis

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This paper presents an axial-flux microelectromechanical systems based (MEMS) micromotor with dual rotors and 10mm diameter. The characteristics of MEMS micromotor are analyzed and modeled using a 3-D magnetic equivalent circuit (MEC) taking the leakage flux and fringing effect into account. Such methodology yields more accurate prediction of the flux distribution inside the machine, back electromotive force waveform and the torque. Furthermore, an investigation of the leakage flux and fringing effect on dimension reduction of the MEMS micromotor is processed. The feasibility of the proposed method is validated by the 3-D finite element analysis (FEA). Finally, the method is applied to design and manufacture the micromotor.

ID: 574 / PC3: 13

Track 13

Topics: Optimization and Design, Novel Computational Methods for Machines and Devices

Keywords: nverse problem, pose detection, magnetic-assisted medical applications, stochastic optimization

Real-time pose detection for magnetic-assisted medical applications by means of a hybrid deterministic/stochastic optimization method

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Some classes of bone fractures are routinely stabilized and aligned by the use of intra-medullary nails. The identification of the pose, i.e. the position and orientation of the drill holes hidden by bone and tissue is currently obtained by X-Ray with all the well known disadvantages of this technology. The idea of substituting this methodology with an eddy-current based one has been explored in previous work but, in spite of interesting features, the developed technique suffered from some shortcomings. In this paper we propose a novel technique which is so computationally efficient that it provides real-time identification performance.

ID: 590 / PC3: 14

Track 19

Topics: Optimization and Design

Keywords: Optimal, Rotor design, PMSM, IPMSM

Optimal Rotor Design of an 150kW-Class IPMSM by the 3D Voltage-Inductance-Map Analysis Method

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A method is presented to determine the detailed design of a 150-kW-class interior permanent-magnet synchronous motor. The basic designs of the stator and rotor were determined. After dividing the designed models into the best and worst cases on the basis of the rotor shape parameters, a sensitivity analysis was conducted, and the three-dimensional voltage–inductance map parameters were analyzed. Then, the design of the final model was predicted. On the basis of this prediction, the final model was extracted with a trend analysis. Finally, the final model was validated with experiments.

ID: 602 / PC3: 15

Track 17

Topics: Optimization and Design, Novel Computational Methods for Machines and Devices

Keywords: Numerical simulations, synchronous motor, industrial drive, 3D effects, end-winding region

Relevance of 3-D Effects in Electromagnetic Simulations of Synchronous Motors for Industrial Drives

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The modern motor design tendency is to develop and manufacture an industrial drive within a short time according to customer specific requirements. Due to their short CPU time analytical methods for motor analysis are still widely used. The existing analytical methods are based on radically simplified models capable of giving enough information for majority of practical design cases. However, the accuracy of analytical methods has to be enhanced in every design usually by introducing different empirical factors in order to capture complicated 2-D and 3-D effects such as magnetic saturation, hysteresis-, eddy current losses and endwinding

effects. This is of paramount importance especially in case of material cost optimization. The purpose of this paper is to present the existing algorithm bases for simulations based 2-D and 3-D analysis of large synchronous motors for industrial drives and by comparing the two to show how relevant is the influence of 3D-effects on the overall accuracy of the electromagnetic simulation of large synchronous motors. Beyond the mentioned numerical aspects, the obtained results are also important for understanding the behavior of the synchronous motor and the entire drive.

ID: 650 / PC3: 16

Track 12

Topics: Novel Computational Methods for Machines and Devices

Keywords: Reduction of the Vibrations in PMSM Based on the Segmentation of the Magnets

A New Investigation on the Reduction of the Vibrations in PMSM Based on Magnets Segmentation

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Permanent magnet synchronous machines (PMSM) have high efficiency and torque density, and have already been employed in hybrid electric vehicles. However, one of their disadvantages is the inherent cogging torque, which is a kind of torque ripple and it would be better to minimize. This torque, sometimes, can be an important source of noise and vibrations. In this paper, the effect of the geometric characteristics of the magnet on the vibratory behavior of electrical machines is illustrated. The optimum geometry for obtaining a minimum vibration level has been reached. For this purpose, an approach by using the Artificial Intelligent (AI) and the Finite Element Method (FEM) is proposed to solve the magneto-mechanical problem of geometrical parameters identification in the optimization process.

ID: 668 / PC3: 17

Track 17

Topics: Optimization and Design

Keywords: FEM, Double Fourier series, Eddy current losses, Power transformer.

Research on Calculating Eddy Current Losses in Power Transformer Tank Walls Using Finite Element Method Combined with Analytical Method

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A new analysis method to calculate eddy current losses in large power transformer tank walls is presented. In this model, the perpendicular flux density has been obtained at discrete points on the surface of the upper face of the tank by Finite Element Method (FEM). Then, double Fourier series is adopted to express the obtained flux density by analytical expressions. The coefficients of the analytical expressions are determined by a least mean error with curve fitting technique and optimization algorithm. Based on the Electromagnetic theory and Maxwell equations, the eddy current losses and distribution are obtained by the analytical formulae. The validation of this approach is verified by TEAM Problem 21 (Model B), showing that the calculation results are in good agreement with measured value. Then, it could be extended to calculate the eddy current losses in the tank walls of power transformer.

ID: 491 / PC3: 18

Track 14

Topics: Numerical Techniques, Novel Computational Methods for Machines and Devices

Keywords: Finite element analysis, Monte carlo methods, permanent magnet machines, response surface methodology

Response Surface Models for the Uncertainty Quantification of Eccentric Permanent Magnet Synchronous Machines

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This work deals with the modelling and simulation of the effect of rotor eccentricity in permanent magnet synchronous machines. Static eccentricity is analyzed in a 2D setting. The 3D effect of an inclined rotor shaft is accounted for considering 2D slices and interpolating on a grid constructed from finite element simulations (response surface model). Common tools of uncertainty quantification, i.e. generalized polynomial chaos and Monte Carlo, are used to study the effect on the electromotive force. The focus of the abstract is the construction of the response surface models used.

ID: 568 / PC3: 19

Track 07

Topics: Static and Quasi-Static Fields, Optimization and Design, Mathematical Modelling and Formulations, Numerical Techniques

Keywords: Finite element analysis, magnetic circuits, magnetostatics, optimization.

Optimization of a Stern-Gerlach Magnet by Magnetic Field-Circuit Coupling and Isogeometric Analysis

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Stern-Gerlach magnets are used to magnetically separate a beam of atoms or atom clusters. The design is difficult since both the magnetic field gradient and its homogeneity should be maximized. This paper optimizes the pole-shoe shapes starting from a reference geometry given in literature. The main contributions of the paper focus on reducing computational time and increasing accuracy, which is achieved by replacing large parts of the model by a magnetic equivalent circuit and by introducing Isogeometric Analysis (IGA) in the remaining field model part, respectively. A highly accurate evaluation of local field quantities is possible thanks to the very smooth field representations, even across elements, offered by IGA's spline-based framework.

ID: 146 / PC3: 20

Track 14

Topics: Electromagnetic Compatibility, Novel Computational Methods for Machines and Devices

Keywords: Design methodology, Microwave devices, Microwave propagation, Radiation safety.

Novel Efficient Strategy to Design an Optimized Microwave Shield

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The purpose of this work is to provide a novel systematic approach to design efficiently a microwave choke for household appliances. In this work, a FEM software has been used to simulate and quantify the EM quantities. The strategy is based on the creation of a reduced model of the choke, in order to achieve less computational complexity. The reduced and the full models are characterized by different response functions, which are compared using a numerical criterion to guarantee consistency between the models. During the design process, a parametric sweep analysis or/and an algorithmic optimization can be applied to achieve the desired EM performances. Experimental validation of the numerical results has been also derived.

PC4: Numerical techniques 2

Time: Wednesday, 01/Jul/2015: 1:45pm - 3:25pm · Location: Cafeteria

Session Chair: Chang-seop Koh

Session Chair: Guglielmo Rubinacci

ID: 11 / PC4: 1

Two Pages Short Version

Topics: Wave Propagation, Numerical Techniques

Keywords: Computational electromagnetics, finite element analysis, mesh generation

Adaption for 2D Edge Elements in the Nonconforming Voxel Finite Element Method

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The nonconforming voxel finite element method (NVFEM) avoids many of the difficulties of traditional finite element mesh generation by using a nested grid of rectangular elements. It models arbitrary boundary shapes by adaptively refining the mesh at the boundaries. Here the adaption is extended to reduce errors arising from elements that are away from boundaries, but are too big to represent the field adequately. The application is to 2D edge elements for solving the time-harmonic wave equation. Results for a miter-bend waveguide problem demonstrate the effectiveness of the new algorithm.

ID: 29 / PC4: 2

Track 20

Topics: Numerical Techniques

Keywords: Computational electromagnetics (CEMs), Harmonic balance finite element method (HBFEM), Multi-frequency domain (MFD)

Overview of Harmonic Balance FEM and its Application in Harmonic Domain Nonlinear EM Field

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The state of the art of harmonic balance finite element method (HBFEM) is to use harmonic balance theories and finite element method based computational electromagnetics (CEMs) technology to analyse or investigate nonlinear electromagnetic fields with harmonic problems in electrical and electronic engineering. HBFEM can directly solve the steady-state response of the electromagnetic field in the multi-frequency domain. The method is often considerably more efficient and accurate in capturing coupled nonlinear effects than the traditional FEM time-domain approach when the field exhibits widely separated harmonics in the frequency spectrum domain and mild nonlinear behavior. This paper presents an overview of HBFEM and its application in solving various harmonic problems related to high frequency transformers, DC biased transformers, and geomagnetic induced currents on transformers.

ID: 79 / PC4: 3

Track 02

Topics: Static and Quasi-Static Fields, Numerical Techniques

Keywords: critical current density, differential algebraic equations, high-temperature superconductors, surface crack

High-Speed Shielding Current Analysis in High-Temperature Superconducting Film with Cracks

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A fast and stable method is proposed for calculating the shielding current density in a high-temperature superconducting film containing cracks. After discretized with the finite element method, the initial-boundary-value problem of the shielding current density reduces to semi-explicit differential algebraic equations (DAEs). Although the DAEs can be solved with standard ordinary-differential-equation (ODE) solvers, much CPU time is required for its numerical solution. In order to shorten the CPU time, a high-speed method is proposed. In the method, the block *LU* decomposition is incorporated into function evaluations in ODE solvers. A numerical code is developed on the basis of the proposed method and, as an application of the code, detectability of cracks by the scanning permanent-magnet method is numerically investigated.

ID: 95 / PC4: 4

Track 19

Topics: Numerical Techniques

Keywords: scattering, Element Free Galerkin Method, Meshless Method, polynomial bases.

Analysis of Polynomial Base Influence in EFG Interpolating Moving Least Square Method Applied to 2D Electromagnetic Scattering

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In this work a study about response of Element Free Galerkin method due to Interpolating Moving Least Square Method is presented using 2D linear, quadratic and cubic polynomial bases. The 2D problem of electromagnetic scattering generated by an infinite dielectric cylinder illuminated by a TMz plane wave is used in the study. A parametric analysis, comparing numerical with analytical results, is carried out in order to identify the best range of value parameters for each base.

ID: 116 / PC4: 5

Track 02

Topics: Optimization and Design, Numerical Techniques

Keywords: adaptive mesh refinement, artificial neural network, electrical capacitance tomography, inverse problem

An Automatic Neural-Networks Based Mesh Refinement Method for Electrical Impedance Tomography

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In real life applications, inverse problems, such as the electrical impedance tomography problem, usually have a limited accuracy, and require huge computation resources to be solved correctly. In electrical impedance tomography, the goal is to obtain the electrical properties of different materials (typically living tissues) by applying an electrical current and measuring the resulting potential difference at the boundaries of the domain. While the maximum numerical accuracy is technically limited by the size of the elements within the finite element mesh, using a fine mesh will result in a computationally demanding reconstruction, especially when the location of the target is unknown. However, this situation is different when the location of the target is known in advance. In this case, one can easily refine the finite element model around the target, allowing a greater accuracy around the region of interest. In this paper, a novel approach estimates the location of the target object before solving the inverse problem, so that it becomes possible to refine only a specific area of the element domain. An artificial neural network is used to determine the location of the target directly from voltages measured at the boundary of the domain. This location is then used to refine the mesh at this specific location, which increases the accuracy without significantly affect the computation resources necessary to solve the inverse problem. Since linear inverse solvers give a linear conductivity distribution, it was decided to use the h-method to refine the mesh around the target object.

ID: 120 / PC4: 6

Track 04

Topics: Numerical Techniques

Keywords: Computational electromagnetics, eddy current evaluation, finite element method, gradient evaluation

Post-Processing of A- ϕ Algorithm for Evaluating Eddy Current Density in Three-Dimensional FEM

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After the vector magnetic potential A and the scalar electric potential ϕ are obtained by the FEM, as the post-processing, the evaluation of electric field intensity E or eddy current density J is an important step, which influences the accuracy of the simulation greatly. Theoretically, E is the sum of the gradient of ϕ and the time-differential of A. However, based on the discrete solution of the FEM, how to evaluate the sum of those two terms concerns methodological issue, for the time-differential of A must be nodal values, but the gradient of ϕ may be element value. The sum of two terms on different positions may create large error. A method for evaluating nodal gradient of ϕ is presented in this paper, to fulfill that the nodal E and J are evaluated by nodal gradient of ϕ and nodal time-differential of A. The presented method is a global evaluation method that evaluates the nodal gradient of ϕ based on the nodal ϕ in the whole field region by setting and solving another equation system of FEM. Certainly, this post-processing method for evaluating E and J consumes some computing time, but the evaluation accuracy can be increased indeed.

ID: 137 / PC4: 7

Track 06

Topics: Static and Quasi-Static Fields, Mathematical Modelling and Formulations, Numerical Techniques

Keywords: Model Order Reduction, Selective Modal Analysis, Large-Scale Electromagnetic Modeling, Dynamical Systems

Model Reduction Techniques for the Analysis and the Design of Large-Scale Electromagnetic Devices

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In the analysis and design of large-scale dynamical systems, simpler models are often preferred to full system models due to their better suitability with computer simulations and real-time constraints. Model reduction techniques aim at yielding a reasonable trade-off between the contrasting needs of reducing the number of states and of reaching a good approximation of the overall system behavior. In the specific case of complex electromagnetic devices (as fusion machines) a large number of state variables represent physical quantities in the overall system, such as currents, voltages, magnetic flux densities and so on. Since it would be important not to lose this valuable feature while reducing the order of the system, we focus on the Selective Modal Analysis (SMA) technique which allows to preserve this meaning resorting to a state selection according to the contribution of the single states to the model modes. The application of various MOR techniques to the numerical models of the ITER machine is discussed.

ID: 143 / PC4: 8

Track 19

Topics: Numerical Techniques

Keywords: Conformal, locally one-dimensional (LOD) finite-difference time-domain (FDTD), numerical dispersion analysis, scattering.

An Efficient Conformal LOD-FDTD Method and its Numerical Dispersion Analysis

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In this paper, an efficient conformal locally one-dimensional finite-difference time-domain (LOD-CFDTD) method is proposed and its theoretical numerical dispersion analysis is presented. Instead of staircasing approximation, the conformal scheme is only employed to model the curved boundaries, whereas the standard Yee grids are used for the remaining regions. As the irregular grids accounts for a very small percentage of the total space grids, the conformal scheme has little effect on the numerical dispersion. With the total-field/scattered-field (TF/SF) boundary and perfectly matched layer (PML), the radar cross section (RCS) of a 2-D structure is calculated to verify the accuracy and efficiency of the LOD-CFDTD method.

ID: 171 / PC4: 9

Track 16

Topics: Numerical Techniques

Keywords: Equivalent circuits, finite element analysis, reduced order systems, inductors, genetic algorithms

Generation of Equivalent Circuit from Finite Element Model of Electromagnetic Devices Using Proper Orthogonal Decomposition

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This paper presents generation of equivalent circuits from finite element (FE) model of electromagnetic devices using proper orthogonal decomposition (POD). This method effectively computes the frequency response of the reduced FE model which is constructed by POD-based model order reduction. Then the lumped parameters for the equivalent circuit are determined so as to minimize the error between the frequency responses of the reduced FE model and circuit. The frequency characteristics of a 3D inductor evaluated by the equivalent circuit are shown to be in good agreement with those computed from the original FE model.

ID: 207 / PC4: 10

Track 19

Topics: Numerical Techniques

Keywords: Periodic Boundary Conditions, Natural Element Methods, Electrical Machines.

Periodic Boundary Conditions in Natural Element Method

Marcio Matias Afonso¹, Bárbara Mara Ferreira Gonçalves¹, Eduardo Henrique da Rocha Coppoli¹, Marco Aurélio de Oliveira Schroeder¹, Rafael Silva Alípio¹, Brahim Ramdane², Yves Marechal²

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In this paper, periodic and anti-periodic boundary conditions are introduced in the Natural Element Method (NEM). These boundaries conditions are important because they allow to explore the inherent symmetry of the electromagnetic devices. It is shown that with these techniques NEM can now easily take advantage of electrical machines symmetry. The proposed approach is evaluated and compared with the traditional Finite Element Method (FEM).

ID: 241 / PC4: 11

Track 04

Topics: Numerical Techniques

Keywords: Numerical analysis, Meshless method, Particle method, Magnetic moment method, Magneto hydro dynamics

Meshless Method Employing Magnetic Moment Method and Particle Method for Magnetic Fluid Motion Analysis

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The Magneto Hydro Dynamics (MHD) phenomena show complex behavior. In this paper, a new meshless method employing the magnetic moment method and the particle method is proposed. The particle method is an analysis method that calculates fluid motion by dividing fluid into small particles. The magnetic moment method is an analysis method that calculates magnetic field by dividing ferromagnetic materials into small elements. In this study, fluid particles in the particle method are treated as ferromagnetic material elements in the magnetic moment method. Therefore, the proposed coupling method does not require calculation points in the air, remeshing in whole space. In this paper, the proposed method is applied to analyze the behavior of magnetic fluid under a magnetic field.

ID: 248 / PC4: 12

Track 15

Topics: Numerical Techniques

Keywords: systems, coupled circuits, direct solvers, finite elements method, sparse matrices

Novel fast algebraic direct method solver for symmetric definite positive systems

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Direct methods of linear algebraic systems solving methods give an exact solution in a definite number of operations. These methods are stable. However, they consume a large memory space for storage. Mesh and graph renumbering methods can accelerate accurately these methods and reducing memory storage. The fastest of these direct methods is the Cholesky method for envelope storage. It has the drawback of being applied only for symmetrical positive definite matrix systems, which represents an obstacle for coupled circuits (electric - magnetic). In this paper, we present a new solution technique faster and more general than the Cholesky method. The methods allow a significant reduction of CPU time consuming which is very suitable in time stepping finite element large problems.

ID: 271 / PC4: 13

Track 11

Topics: Numerical Techniques

Keywords: Finite element analysis, Eddy currents, Reduced order systems, Nonlinear equations, Adaptive algorithms

A self-adaptive model-order reduction algorithm for nonlinear eddy current problems based on quadratic-linear modeling

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Finite-element time-domain simulations of nonlinear eddy current problems require the solution of a large, sparse system of equations at every time step. Model-order reduction is a powerful tool for reducing the computational effort for this task. In this paper, an adaptive order-reduction methodology with error control is proposed. In contrast to previous approaches, it treats the nonlinearity without simplification, by rewriting the original equations as a quadratic-linear system.

ID: 307 / PC4: 14

Track 16

Topics: Electromagnetic Compatibility, Numerical Techniques, Multi-physics and Coupled Problems

Keywords: Finite difference methods, finite element analysis, HVDC transmission, nonlinear equations, space charge

Calculation of Ion-Flow Field of HVDC Transmission Lines in the Presence of Wind Using Finite Element-Finite Difference Combined Method with Domain Decomposition

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A new combined method adopting the domain decomposition is proposed for analyzing the ion flow field of HVDC transmission lines including the effect of the transverse wind. The calculation process of the Poisson equation is iterated with Dirichlet-Neumann algorithm to coordinate the solution between adjacent subdomains. The upstream finite element method is used with dense triangle mesh in the vicinity of bundles conductors to guarantee the accuracy where the electric field strength changes severely. The upstream finite difference method is proposed and the larger uniform quadrilateral grid is applied to simulate the ion flow field in the rest of the region to reduce the amount of the meshes with a satisfactory precision. Suitable methods and reasonable distribution of the grid can be used in different subdomains to improve the calculation efficiency. Finally calculations are well compared with experimental data and results in the presence of wind in the previous literature.

ID: 342 / PC4: 15

Track 06

Topics: Numerical Techniques

Keywords: Equivalent circuits, finite element analysis, reduced order systems.

Generation of Equivalent Circuit from Finite Element Model Using Model Order Reduction

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This paper presents a novel generation method of equivalent circuits for FE model of electromagnetic devices using model order reduction (MOR) based on Padé approximation via the Lanczos process (PVL). In this method, an equivalent circuit is directly generated from the reduced transfer function which is obtained using MOR based on PVL algorithm. It is shown that the generated circuit yields sufficiently accurate results in both frequency and time domains. Moreover, the computational time required for the present method is much shorter than identification of circuit parameters by frequency sweep based on the original FE models.

ID: 421 / PC4: 16

Track 04

Topics: Numerical Techniques

Keywords: Boundary value problems, Green's function methods, Integral equations, numerical analysis, plasma simulation

Numerical Technique Based on Extended Boundary Node Method for Solving Grad-Shafranov Equation

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The extended boundary node method (X-BNM) has been applied to the boundary-value problem of the Grad-Shafranov (G-S) equation and its performance has been numerically investigated by comparing with the dual reciprocity boundary element method (DRM). The result of computations shows that the accuracy of the X-BNM is higher than that of the DRM. Therefore, it is found that the X-BNM might be a powerful tool for solving the boundary-value problem of the G-S equation.

ID: 505 / PC4: 17

Track 10

Topics: Numerical Techniques

Keywords: Eddy currents, Degenerated Whitney element, Thin Region, Anisotropic material, Laminated CFRP.

Degenerated hexahedral Whitney elements for electromagnetic fields computation in multi-layer anisotropic thin regions

Huu Kien BUI, Guillaume Wasselynck, Didier Trichet, Gérard Berthiau

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In this article, the use of degenerated hexahedral Whitney elements method in the modeling of multi-layer anisotropic regions is presented. These elements degenerated from hexahedral elements are used to model laminated composites in the scale of one ply taking into account the circulation of eddy-currents along the thickness of the material. Eddy current problem is solved using A

ID: 603 / PC4: 18

Track 19

Topics: Numerical Techniques

Keywords: Numerical simulation, finite difference methods

An Advanced Numerical Technique for Low Frequency Electromagnetic Field Simulation based on Finite-Difference Time-Domain Method

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In this paper, an advanced numerical technique is proposed for the low frequency electromagnetic field simulation. The finite-difference time-domain (FDTD) method is one of the best methods to analyze electromagnetic field problems which require high-precision, such as a heterogeneous whole-body voxel human model. However, directly using the standard FDTD method in the quasi-static frequency band requires an extra-large number of iterations. We overcome this drawback by modifying the FDTD method which employs a quasi-static behavior with the surface equivalence theorem. The results of our method are in good agreement with those from a commercial electromagnetic simulator.

ID: 610 / PC4: 19

Track 15

Topics: Electromagnetic Compatibility

Keywords: Demagnetization, Surface Permanent Magnet Motor, End-effect, Armature reaction

A Study of End-effect on Demagnetization in Surface Permanent Magnet Motor without Overhang

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In order to compensate the low performance of ferrite magnet, surface permanent magnet mounted (SPM) motor has considerably thicker magnet than air-gap length, thus end effect, which is determined by the ratio between magnetic air-gap and stack length, is negligible. As a result, 2-D finite element analysis (FEA), which is not possible to consider end effect, is generally used to ensure analysis accuracy in SPM motor without overhang structure. However, unlike other analysis such as back-EMF, demagnetization analysis of SPM cannot be ensured by 2-D FEA, because end effect is no longer ignored. In the demagnetization, magnetic air gap, which determines the level of end effect, is increased by the fact that the permeability of magnetized magnet is almost similar to vacuum, thus only 3-D FEA is used to ensure analysis accuracy. We have found this phenomenon by comparison between the results of 2-D and 3-D FEA, and finally we are plan to validate the simulation result by experiment test.

ID: 642 / PC4: 20

Track 12

Topics: Mathematical Modelling and Formulations, Numerical Techniques

Keywords: Finite element method, domain method, multiple multipole program, boundary method, nonlinear materials

Generalized Multiple Multipole Program for Nonlinear Materials

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Multiple Multipole Program (MMP) is a boundary method for computing electromagnetic fields well established in high frequency electromagnetics and computational optics due to its flexibility in terms of accuracy control, field excitation, and fast convergence. As any other boundary method also MMP in its original form cannot solve nonlinear problems. The purpose of this paper is to show a novel numerical method for treating local nonlinear regions within a large MMP linear model. The main idea of this approach is to apply the well-known discretization scheme of the domain Finite Element Method (FEM) within the nonlinear region and to couple it over a special numerical interface with the linear MMP model surrounding it. The theoretical details of this MMP-FEM coupling and practical examples of it are presented in this paper.

ID: 442 / PC4: 21

Track 10

Topics: Static and Quasi-Static Fields, Numerical Techniques

Keywords: Surface impedance, parametric solutions, small skin depth

Efficient delta-parametrization of 2D Surface-Impedance solutions

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The impedance boundary condition methods (IBCs) are among the most efficient for solving time-harmonic eddy-current problems with a small skin depth (δ). When the solution is required for a wide range of frequencies (or material conductivities) the standard approach is not efficient, because it leads to the solution of a finite element (FE) complex-valued problem for each frequency (or conductivity). Moreover, the error of IBC grows much too quickly with δ . As an extension of previous work, we propose here in more details a possible method of parameterization in δ of the 2D small- δ eddy-currents problem. This numerically efficient method gives a very good precision for all the "difficult" frequencies, that means from the frequency corresponding to the last good solution obtainable by meshing the conductor, to the infinite limit (perfect conductor solution).

ID: 133 / PC4: 22

Track 18

Topics: Numerical Techniques

Keywords: Computational modeling, Numerical analysis, Iterative methods, Convergence of numerical methods

Modeling and Computational Method for Air-core Winding Based on the Overlapping Partitioning Waveform Relaxation

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In this paper, an elaborate broadband model for the air-core winding is created based on the partial element equivalent circuit (PEEC) approach in order to study the internal overvoltage under the lightning transients. Because the large scale of the resulting model makes it difficult to be solved directly, the waveform relaxation method combined with the overlapping partitioning techniques is used. In this method, the whole network is divided into many sub-circuit and solved separately based on the analysis of the winding's coupling parameters. Furthermore, the relationship of the convergence rate between the number of the overlapping areas is also discussed. In order to validate the method, an experiment air-core winding is studied, and a conclusion is achieved that the rate of the convergence can be improved greatly by using the overlapping partitioning techniques.

ID: 589 / PC4: 23

Track 07

Topics: Optimization and Design

Keywords: Design optimization, inverse problem, multiobjective, tabu search algorithm.

A Vector Tabu Search Algorithm with Enhanced Searching Ability for Pareto Solutions and its Application to Multiobjective Optimizations

Jiaqiang Yang, Shiyong Yang, Suming Xiong, Peihong Ni

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A vector tabu search algorithm encapsulating a new updating mechanism for current state and a directed search phase is proposed to enhance its searching ability for Pareto solutions. The new updating mechanism considers quantitatively both the number of improved objectives and the amount of improvements in a specified objective. The directed search phase uses some desired directions, a priori knowledge about the objective space, as the moving direction to efficiently find improved solutions without any gradient computation procedure. The numerical results on a high frequency inverse problem are reported to demonstrate the pros and cons of the proposed algorithm. It is observed that the proposed vector tabu search method outperforms its ancestors in both convergence performance and solution quality.

PC5: Material modeling 2

Time: Wednesday, 01/Jul/2015: 1:45pm - 3:25pm · *Location:* Lounge

Session Chair: Dennis D Giannacopoulos

Session Chair: Frederic Sirois

ID: 76 / PC5: 1

Track 11

Topics: Material Modelling

Keywords: Finite element methods, fixed point method, hysteresis, magnetic materials

An Adaptive Fixed Point Iteration Algorithm for Finite Element Analysis with Magnetic Hysteresis Materials

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In this paper, an adaptive fixed point iteration algorithm for 2D/3D FEA with magnetic hysteresis is proposed. The iteration starts with the B-correction scheme. If the solution is not converged to a given accuracy after a certain number of iterations, the iteration will be continued by switching to the H-correction scheme. Based on the combined use of the two correction schemes during the whole iteration process, the solution with the minimum error together with the scheme type is recorded and will be used as the final solution at the current time step. At the same time, the recorded scheme type will be used as the initial scheme type for the next time step. The numerical validation shows that the proposed algorithm not only has very fast convergence rate, but is also very stable.

ID: 86 / PC5: 2

Track 17

Topics: Material Modelling

Keywords: Dielectric constant, oil-paper insulation, fractional calculus, numerical computation

Modeling for Frequency Characteristics of Oil-paper Composite

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Oil-paper composite insulation is an important part of insulation of the transformer equipments and its circuit mode plays an important role in researching influence of the frequency-dependent dielectric constant on transformer model. From the basic theory of dielectric, fractional theory is used to improve the present integer-order circuit model of oil-paper composite insulation and fractional circuit model of oil-paper composite insulation is proposed preliminarily. Then, the proposed fractional circuit model has been verified by dielectric spectroscopy of oil-paper composite insulation. Finally, by comparing the fitting residuals of the integer-order model and fractional model and using proposed fractional circuit model to fit polarity reversal voltage response of oil-paper composite insulation, the conclusion can be drawn that fractional model in this paper has feasibility and veracity.

ID: 107 / PC5: 3

Track 12

Topics: Material Modelling

Keywords: Temperature dependance, magnetic losses, thermal stresses

Temperature dependent extension of a hysteresis model

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Some soft magnetic materials (like ferrites but not only) are strongly dependent of the temperature. In order to predict their behaviour in electrical devices, engineers need hysteresis models able to take into account the temperature. This paper is an attempt to take into account the temperature in an existing model of hysteresis through its parameters. Variations of some parameters are issued from Weiss's works and others have to be fitted numerically. Simulation results are compared to measurements and discussed.

ID: 157 / PC5: 4

Track 05

Topics: Material Modelling

Keywords: Electromagnetic fields, finite element methods, magnetic hysteresis.

Improvement of Identification Method for Isotropic Vector Play Model

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In order to accurately estimate the iron loss for rotating machinery, this paper proposes the novel identification method for the hysteresis model by using the isotropic vector play model so as to accurately represent the rotational hysteresis loss of magnetic materials. The numerical results are compared with the conventional identification method to demonstrate the effectiveness of the proposed identification method.

ID: 179 / PC5: 5

Track 16

Topics: Material Modelling

Keywords: Critical surface, micromagnetics, Preisach modeling, vector hysteresis.

Vector Hysteresis Modeling Based on Energy Homogenization

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In various applications, the magnetic hysteresis modeling must ensure that both the magnitude and direction of the magnetization are quantified correctly. To this end, extensive studies have been made in the context of Preisach modeling. Inspired by the recently proposed Preisach-Stoner-Wohlfarth model, a magnetic hysteron, is proposed in a more generalized energy framework, whose behavior is in agreement with the required thermodynamic properties. This hysteron can also be used to establish the relationship between the critical surface and the angular variation of magnetization, which is based on a different expression. In this paper, an efficient and self-consistent vector hysteresis model is proposed. The proposed model simulates the macroscopic ferromagnetic properties in the real media and is validated experimentally.

ID: 183 / PC5: 6

Track 04

Topics: Material Modelling

Keywords: Cauer realization, dynamic hysteresis, Legendre polynomial, pulse width modulation

Cauer Circuit Representation of Homogenized Eddy-Current Field Based on Legendre Expansion in Magnetic Sheet

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Using the Legendre expansion of magnetic field distribution, this article derives the standard Cauer circuit representation of the frequency-dependent properties of magnetic sheets and discusses the physical meaning of the standard Cauer circuit. The Cauer circuit is applied to the dynamic hysteresis modeling of silicon steel under the PWM excitation.

ID: 186 / PC5: 7

Track 02

Topics: Nano-Electromagnetic Computation, Numerical Techniques

Keywords: Computational electromagnetic, convergence of numerical methods, discrete geometry method, surface plasmons

Error Estimation of Discrete Geometry Method (DGM) on Plasmonic Structures

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We derive the local and global discretization error of the discrete geometry method (DGM) on a plasmonic structure. Based on a structured discretization of the computational domain, two cases of field distributions are considered: one with electric field distributed on primal mesh and magnetic field on dual mesh, the other conversely. The analysis shows that when the magnetic field is placed on primal mesh, the numerical scheme approximates the continuous problem better than the case when electric field are placed on primal mesh. The convergence rate for both cases are calculated.

ID: 210 / PC5: 8

Track 06

Topics: Optimization and Design, Material Modelling

Keywords: Cloaking, Coordinate transformation, Electromagnetic metamaterials, Scattering cross section

Analysis of the out-of-plane Coordinate Transformation to obtain Anisotropic Layered Cloaks

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A possible strategy for avoiding singular material parameters in a transformation-based cloak involves an out-of-plane stretching, calculated to compensate the in-plane singular transformation. In this paper, we use numerical simulations to analyze the relation between the out-of-plane transformation, the resulting material anisotropy and the total scattering cross width. Moreover, because discretization in layers is a common step in a practical design, we also explore its influence, considering a further optimization stage.

ID: 234 / PC5: 9

Track 08

Topics: Material Modelling

Keywords: Excess losses, magnetic materials, numerical analysis, silicon steel plate.

Numerical Calculation of the Excess Loss in Magnetic Sheet Considering Domain Wall Bowing

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In this paper, the numerical calculation of iron loss in silicon steel plates considering the domain wall bowing is carried out. The domain wall bowing, which contributes to the excess loss, is considered by applying an initial flux distribution along the sheet thickness into a nonlinear eddy current finite element analysis. The initial flux distribution is assumed to take the shape of parabola with different wall bowing degrees and average values. The iron loss including the excess loss can be calculated using the obtained flux and eddy current density directly. In the range of 100 Hz ~ 1000 Hz, the calculated iron losses are compared with the measured data in the catalogue, 5% maximum error is achieved.

ID: 258 / PC5: 10

Track 11

Topics: Static and Quasi-Static Fields, Numerical Techniques, Material Modelling

Keywords: Magnetic hysteresis, Newton Method, Finite element analysis

Inclusion of a Direct and Inverse Energy-Consistent Hysteresis Model in Dual Magnetostatic Finite Element Formulations

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This paper deals with the implementation of an energy-consistent ferromagnetic hysteresis model in 2D finite element computations. Being naturally vectorial, the hysteresis model relies on a strong thermodynamic foundation and ensures the closure of minor hysteresis loops. The model accuracy can be increased by controlling the number of intrinsic cell components while parameters can be easily fitted on common material measurements. Here, the native h -based material model is inverted using the Newton-Raphson method for its inclusion in the magnetic vector potential formulation. Simulations are performed on a 2D T-shaped magnetic circuit exhibiting rotational flux. By way of validation, comparison is made with results obtained by the dual magnetic scalar potential formulation. A very good agreement for global quantities is observed.

ID: 287 / PC5: 11

Track 09

Topics: Electromagnetic Compatibility, Numerical Techniques

Keywords: eddy currents, nonlinear magnetics, magnetic hysteresis, magnetic losses

Numerical computation of electromagnetic fields in axisymmetric laminated media with hysteresis

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This work deals with the computation of transient electromagnetic fields in magnetic media with hysteresis. The classical Preisach model for hysteresis is considered. We assume axisymmetry of the fields. The magnetic field on the boundary of the domain is given as a source term. For the numerical solution, a space discretization by nodal finite elements and a backward Euler time-discretization are used. To deal with the non-linearities, we propose an iterative algorithm based on the properties of maximal monotone operators. The numerical scheme is validated with experimental results. In particular, we compare the eddy current and hysteresis losses obtained from the numerical computations with experimental ones.

ID: 350 / PC5: 12

Track 11

Topics: Numerical Techniques, Material Modelling

Keywords: Magnetic properties, Non-Oriented steel sheets, Anisotropy

Models of magnetic anisotropy for non oriented steel sheets dedicated to finite element method

Floran Martin, **Deepak Singh**, **Paavo Rasilo**, **Anouar Belahcen**, **Antero Arkkio**

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Even non oriented steel sheets present anisotropic behavior. Our investigation consists of developing two models based on rotational measurements to consider these magnetic properties. The direct method models both components of the magnetic field with the ones of the magnetic flux density. The indirect method determines the energy density as a function of the magnetic flux density. The magnetic field is then calculated by differentiating the energy density with respect to the magnetic flux density. Both models are finally validated by comparing measured and computed values of the magnetic field.

ID: 354 / PC5: 13

Track 04

Topics: Material Modelling

Keywords: Anisotropy, magnetic energy, play model, vector hysteresis.

An Anisotropic Vector Play Model Using Decomposed Shape Functions

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This paper proposes a new anisotropic vector play model using the decomposition of vector shape functions. The parallel and perpendicular components of magnetic field \mathbf{H} to the magnetic flux density \mathbf{B} are independently identified to construct decomposed shape functions. This paper further proposes a method to reconstruct the perpendicular component from the one-dimensional (1-D) measurement of parallel component based on a magnetic energy approach.

ID: 381 / PC5: 14

Track 11

Topics: Mathematical Modelling and Formulations, Material Modelling

Keywords: Cauchy problem, Maclaurin series, magnetic hysteresis, magnetic materials.

An Improved Methodology for Obtaining Jiles-Atherton Hysteresis Model Parameters

Filomena Barbosa Rodrigues Mendes^{1,2}, **Jean Vianei Leite**¹, **Nelson Jhoe Batistela**¹, **Nelson Sadowski**¹, **Fredy Maglorio Sobrado Suárez**²

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An accurate material modeling is imperative for field calculations in order to assure reliable results. For hysteresis modeling the Jiles-Atherton approach has been broadly employed but it is strongly dependent on its parameter set to work appropriately. This paper presents an original methodology to obtain such parameters. From the model equations, two non-linear algebraic systems of five equations and five parameters are written. In order to validate the methodology, experimental data are compared to calculated ones. Simulations demonstrate that the proposed methodology obtain an accurate parameters set from experimental hysteresis loop with relative low computation effort.

ID: 414 / PC5: 15

Track 11

Topics: Material Modelling

Keywords: Eddy current, magnetic anisotropy, magnetic losses, magnetic materials

Modelling Eddy Current Losses in Anisotropic Electrical Steel under Rotational Magnetic Field**Anouar Belahcen^{1,2}, Deepak Singh¹, Florian Martin¹, Paavo Rasilo¹**¹Aalto University, Department of electrical Engineering and AutomationFinland; ²Tallinn University of Technology, Department of electrical Engineering; anouar.belahcen@aalto.fi

This paper presents a methodology to model magnetic anisotropy in electrical steel as well as the computation of Eddy current losses under such anisotropy. The parameters of the anisotropic model are estimated from measurements under rotational flux density. The computation of the Eddy current losses is performed with an advanced one-dimensional numerical model, where the skin effect is accurately accounted for. The results show that only few harmonic terms of the magnetic reluctivity are needed to achieve good accuracy. Further, the results from the Eddy current model show that the losses depend strongly on the reluctivity.

ID: 425 / PC5: 16

Track 06

Topics: Material Modelling

Keywords: Magnetic Flux density, Magnetic loss, Harmonic analysis, Finite element analysis, Fourier series

Measurement and Computation of Rotational Core Loss Considering Higher Harmonic Components of Magnetic Flux Density Waveform**Yanli Zhang, Zheng Cao, Dianhai Zhang, Ziyang Ren, Baodong Bai, Dexin Xie**Shenyang University of Technology, China, People's Republic of; zhangyanli_sy@hotmail.com

This paper presents a simplified method of calculating rotational loss of electrical steel sheet under distorted magnetic flux density condition, in which the non-sinusoidal magnetic flux density (B) waveform is expanded into fundamental and higher harmonic components using Fourier series expansion, and the trajectory of B vector tip is described as the overlap of several elliptical loci at different frequency. The total loss under distorted B is calculated from the sum of loss at different frequencies measured by a two-dimensional (2-D) magnetic property testing system. By comparing the simulation results with experimental test ones for a motor iron core model, the effectiveness of the proposed method is verified.

ID: 456 / PC5: 17

Track 17

Topics: Optimization and Design, Material Modelling

Keywords: Power transformer, integrated magnetic, magnetic material, hysteresis and electromagnetic coupling

DC bias Elimination and Integrated Magnetic in Power Transformer**Baodong Bai, Zhiwei Chen, Dezhi Chen**Shenyang University of Technology, China, People's Republic of; baodongbai@163.com

This paper studies the DC bias phenomenon of power transformer and integrated magnetic. A new transformer with function of DC bias elimination is designed based on nano-composite magnetic material and a controllable reactor is integrated into the transformer via integrated magnetic technology. Mathematical model of hysteresis of the magnetic material is established and the correspondence relationship between coercivity and remanence of this material is determined; DC magnetic potential in transformer core can be eliminated directionally using the conversion of coercivity and remanence. The integrated controllable reactor has the notable characteristics of decoupling with other windings, high linearity, less extra covering area, and energy saving[1]. It also can be used for power system reactive power compensation which verifies the correctness and feasibility of the design.

ID: 460 / PC5: 18

Track 18

Topics: Material Modelling, Multi-physics and Coupled Problems

Keywords: coercive force, Iron alloys, magnetoelasticity, magnetostatics, stress.

Coercivity in Soft Magnetic Material under Alternative Mechanical Stress**Olivier Ghibaudo, Hervé Chazal, Nicolas Galopin, Lauric Garbuio**Univ. Grenoble Alpes, G2Elab-CNRS, F-38000 Grenoble, France, France; olivier.ghibaudo@g2elab.grenoble-inp.fr

The mechanisms leading to coercivity reduction under dynamic mechanical stress obtained on soft ferromagnetic samples are modelled. The coercive forces related to magnetoelastic anisotropy fluctuations are investigated in polycrystalline magnetic materials to quantify the effects of applied dynamical mechanical stress. Domain Wall displacement is so reconsidered and mechanism allowing magnetization reversal in magnetoelastic defects is explained. Therefore, energy barriers that pin domain wall at the mesoscopic scale of the magnetoelastic defects are analytically calculated and the cooperative behaviour between magnetoelastic defects due to magnetostatic energy is emphasized. Finally, the coercive field decrease is estimated and compared to measurements on Fe49Co49V2 material.

ID: 472 / PC5: 19

Track 11

Topics: Static and Quasi-Static Fields, Numerical Techniques, Material Modelling

Keywords: Magnetic hysteresis, magnetic materials, vector hysteresis

Improvements in a Jiles-Atherton Vector Hysteresis Model**Juliano Bitencourt Padilha, Jean Vianeil Leite, Nelson Sadowski, Patrick Kuo-Peng, Nelson Jhoé Batistela**GRUCAD/EEL/CTC/UFSC, Brazil; jean.vianeil@ufsc.br

Electromagnetic devices can experiment alternating and/or rotational magnetic fluxes. Alternating and rotating losses are associated to these fluxes, wherein the rotating components are generally larger than the alternating ones and concentrated in particular areas of rotating electrical machines and transformers. Under rotational flux conditions a vector relationship between field and induction must be

considered. The phenomenon of magnetic hysteresis under rotating flux is only conveniently modeled with vector hysteresis models as the Jiles-Atherton vector version employed in this work, in which some modifications are performed in order to improve its behavior.

ID: 527 / PC5: 20

Track 05

Topics: Numerical Techniques

Keywords: Eddy current, high order enrichment function, nearby geometrical interfaces, XFEM.

An Improved XFEM for Field Analysis of Multilayer HTS Tapes with Multiple Nearby Geometrical Interfaces

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This paper proposes an improved extended finite element method (XFEM) for modeling high temperature superconducting (HTS) tapes with multiple nearby geometrical interfaces. In regions near these interfaces, the magnetic vector potential approximation is enriched by incorporating multiple derivative discontinuous fields based on the partition of unity method such that the interfaces can be represented independent of the mesh. The support of a node or an element can be cut by several interfaces. This method results in the high accuracy in the approximation field and the derivative field. Numerical examples applied to the multilayer HTS tapes in 2D eddy current field involving level set based parts, error analysis and electromagnetic field computations are provided to demonstrate the utility of the proposed approach.

ID: 541 / PC5: 21

Track 12

Topics: Material Modelling

Keywords: Eddy currents, finite element analysis, magnetic losses, skin effect

New approach for Accurate Prediction of Eddy Current Losses in Laminated Material in the Presence of Skin Effect with 2D FEA

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The integrated iron loss models in FE software overestimate the eddy current losses at high frequencies due to the presence of the skin-effect. This paper presents a simple detour for accurate prediction of eddy current losses in laminations with two-dimensional (2D) finite element analysis (FEA). An experimental set-up along with the simulation models is used to demonstrate the validity of the method. The utility of this method in loss separation and identification of loss coefficients is also illustrated.

ID: 67 / PC5: 22

Track 04

Topics: Material Modelling, Multi-physics and Coupled Problems, Novel Computational Methods for Machines and Devices

Keywords: Coupled Problems, Finite Element Analysis, Hysteresis Modeling, Induction Generator, Electrical Machines

Vector Hysteresis Model Associated to FEM in a Self-Excited Induction Generator Modeling

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This paper discusses the implementation of the inverse Jiles-Atherton (JA) vector hysteresis model with 2D FEM for the analysis of an induction machine operating as self-excited generator. A differential reluctivity tensor couples the hysteresis model with the magnetic vector potential based FE model. Experimental and simulated results are presented.

PC6: Nano-electromagnetic computation; Photonics and optoelectronics

Time: Wednesday, 01/Jul/2015: 1:45pm - 3:25pm · Location: Lounge

Session Chair: Istvan Bardi

Session Chair: Kurt Preis

ID: 474 / PC6: 1

Track 02

Topics: Nano-Electromagnetic Computation

Keywords: Microwave-assisted magnetic recording, Microwave oscillator, Finite element analysis, Micromagnetics

Analysis of Spin Torque Nano-Oscillator for Microwave Assisted Magnetic Recording

Yuanyuan Guo^{1,2}, Xiaoguang Li^{1,2}, ZHEJIE LIU³

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This paper studies the performance of a spin torque nano-oscillators which is integrated with a perpendicular write head for microwave assisted magnetic recording systems. The write head generates both out-of-plane and the in-plane components of the magnetic field in the field generation layer of the spin torque oscillator. It is found that the magnetic writer field has significant influence on the oscillator performance which needs to be taken into consideration in design of the writer heads for a microwave assisted magnetic recording system.

ID: 630 / PC6: 2

Track 08

Topics: Wave Propagation, Photonics and Optoelectronics

Keywords: Geometrical optics, Optical Imaging, Optical Metamaterials, Optical Propagation

Calculation of Imaging Properties of Metamaterials

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Metamaterials have extraordinary optical properties, which can be utilized in novel imaging systems. Their imaging properties, however, cannot be determined by simple geometrical optics. Here we propose a method that combines full wave simulation, transfer matrix method and geometrical optics to efficiently simulate imaging systems containing metamaterials. The dispersion relation of a periodic metamaterial slab is retrieved from S parameters obtained from full wave simulation of the unit cell. The dispersion relation is used to calculate the field produced by a point source behind a metamaterial slab. Finally, light rays are derived from the full wave solution to obtain the virtual image of the point source. From the virtual distance an effective geometrical refractive index is determined, which can describe the imaging properties of the metamaterial. The imaging properties of a Fishnet metamaterial are investigated using the developed procedure.

ID: 675 / PC6: 3

Track 09

Topics: Nano-Electromagnetic Computation

Keywords: polycrystalline, magneto-elastic, magnetic anisotropy, micromagnetics

Micromagnetics Numerical Method for Rotational Magnetization of SMC Material Considering Magnetoelastic Effect

Changqeng Zhang¹, Qingxin Yang^{1,2}, Yongjian Li¹, Erping Li¹

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²Tianjin Key Laboratory of AEEET Tianjin Polytechnic University; chang_qeng@sina.com

This paper analyzes the magnetic anisotropy of the soft magnetic composite (SMC) material which is observed in rotational magnetic properties measurement. It proves that magneto-elastic effect brings out magnetic anisotropy for pure iron particle with a single domain. And then a new micromagnetics numerical method is developed to consider magneto-elastic effect for polycrystalline iron particle under the framework of OOMMF. The simulation shows that magnetoelastic energy may cause magnetic anisotropy characteristic in the SMC material.

ID: 687 / PC6: 4

Track 18

Topics: Nano-Electromagnetic Computation

Keywords: Perpendicular magnetic recording, Nanostructured materials, Magnetic heads, Micromagnetics

Evaluation of Write Field and Media Response For Shingled Magnetic Recording

Xiaoguang Li^{1,2}, Yuanyuan Guo^{1,2}, Zhejie Liu³

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An evaluation of the shingled magnetic recording performance is presented based on combined analysis of the magnetic write field and medium responses. The writer structure is featured with the asymmetrically shielded main pole having a slot between the trailing shield and the side shield at the shingled writing edge. In order to account for the angle dependence of the magnetization reversal behavior, the effective write field profile is studied on the basis of micromagnetic modeling of the medium characteristics solving Landau-Lifshitz-Gilbert equation. In particular, the effective field gradients are examined at various critical locations of the write field contour. It is found that the aforementioned slot may be used to modulate the effective field gradient near the shingled writing corner and the combined analysis can be efficiently applied to perform analyses of the medium noise and erase band width.

OA6: Material modeling

Time: Wednesday, 01/Jul/2015: 3:50pm - 5:30pm · *Location:* Room #0100

Session Chair: Hajime Igarashi

Session Chair: Ruth V. Sabariego

ID: 706 / OA6: 1

Two Pages Short Version

Topics: Material Modelling

Keywords: Electrical machines, ferromagnetic materials, Jiles Atherton model, iron losses

Prediction of Iron Losses Using a Jiles-Atherton Model with Interpolated Parameters under the Conditions of Frequency and Compressive Stress

Sajid Hussain, David Alister Lowther

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The operating conditions such as frequency of excitation, stress and temperature in electrical machines severely affect the magnetic behavior of ferromagnetic cores which translates into increased iron losses. Physics-based hysteresis models such as the Jiles-Atherton (JA) model can incorporate the effects of operating conditions on iron losses. In addition to this, these models can be embedded in finite element simulations. In this work, we have implemented the JA model to predict iron losses and the effect of the frequency of the excitation waveform; and compressive stress on JA model parameters has been investigated. A simple approach is proposed to predict iron losses for any value of frequency and compressive stress using the original JA model equation. This approach not only reduces the computational complexity of the problem but also reduces the amount of material information required.

ID: 470 / OA6: 2

Track 18

Topics: Mathematical Modelling and Formulations, Numerical Techniques, Material Modelling

Keywords: dynamic modeling, eddy currents, finite-differences method, finite-element method, magnetic hysteresis, power loss

Comparison of Different 1-D Models for the Calculation of Magnetization Dynamics in Non-Oriented Soft Magnetic Steel Sheets

Martin Petrun¹, Simon Steentjes², Kay Hameyer², Drago Dolinar¹

¹University of Maribor, Slovenia; ²RWTH Aachen University; martin.petrun@um.si

This paper presents the comparison of different 1-D nonlinear dynamic models of non-oriented soft magnetic steel sheets (SMSSs). The discussed models take into account dynamic effects on magnetization due to eddy currents and hysteresis inside such sheets and differ in the way the coupled Maxwell equations with hysteresis are solved. Finite-difference and finite-element approaches are used to solve the strongly coupled problem. In contrast to this, an alternative modelling approach is based on Ampere's and Faraday's laws, where a system of ordinary differential equations is obtained when using adequate discretization. The different modelling approaches are analysed and compared in terms of mathematical structure, implementation work, spatial discretization and accuracy.

ID: 697 / OA6: 3

Two Pages Short Version

Topics: Material Modelling

Keywords: Finite difference method; Finite element method; Graphene; Surface boundary condition.

A Provably Stable and Simple FDTD Formulation for Electromagnetic Modeling of Graphene Sheets

Fatemeh Afshar, Ali Akbarzadeh-Sharbat, Dennis D Giannacopoulos

McGill, Canada; fatemeh.afshar@mail.mcgill.ca

A new finite-difference time-domain (FDTD) formulation for modeling Graphene is proposed, in which Graphene is modeled as a resistive sheet with a frequency-dependent conductivity. The formulation is first developed in the context of the vector wave finite-element time-domain (FETD) and then reduced to the FDTD based on the equivalence between these two techniques. The obtained formulation is easy-to-implement and does not alter the original FDTD update equations. It can be applied to an existing FDTD code by simply adding a correction term to the appropriate variables. One of the main contributions of the paper is analyzing the stability of the proposed formulation, which has not been done previously.

ID: 203 / OA6: 4

Track 15

Topics: Electromagnetic Compatibility, Multi-scale modelling and homogenization, Novel Computational Methods for Machines and Devices

Keywords: Homogenization, Thin sheets, Finite Element Method (FEM), Shell elements, Periodic structures, Frequency Selective Surface (FSS).

Modeling Layered Structures by Shell Elements Using the Finite Element Method

Istvan Bardi, Guanghua Peng, Rickard Petersson

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A novel, two step method is presented to model thin or thick layered homogeneous or periodic structures replacing them by 2D sheets with shell elements. A unit cell model of the thin/thick 2D structure is used to extract the circuit Y matrix which characterizes the layer. Degenerated prism elements modeled as shell elements are applied by doubling the essential variables on the surface. The link between the two sides of the surface is governed by the circuit Y matrix obtained from the unit cell model. This way, shielding effects can be accurately and efficiently modeled by using the Finite Element Method without 3D meshing the layer(s).

ID: 199 / OA6: 5

Track 08

Topics: Static and Quasi-Static Fields, Material Modelling

Keywords: Superconducting numerical models, Multifilamentary superconductors, AC losses

3D Numerical Modeling of AC Losses In Multi-filamentary Superconductors

Guillaume Escamez^{1,2}, Arnaud Badel², Pascal Tixador², Brahim Ramdane³, Gérard Meunier³, Arnaud Allais¹, Christian-Eric Bruzek¹, Frederic Sirois⁴, Roland Rivard⁴, Steven Dufour⁴

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MgB2 superconductors show great potential for the high current compact power cables. Throughout the design of the cooling system for a 12 kA cable, the losses has to be calculated as close as possible. This article focuses on the calculation of AC losses generated by a time varying environment as AC current or/and external magnetic field. The superconductor AC loss modeling problem can be formulated as an eddy current problem in which the resistivity of the superconducting region is modeled with a power law characteristic. However, the calculation of AC losses for superconductors in 3-D, using the finite element method, is time consuming and leads to convergence issue due to the very nonlinear nature of the power law E-J characteristic, as well as the singular behavior of the flux/current front everywhere where the current density is zero. In this paper, two electromagnetic formulations as well as two different E-J models have been studied and compared in order to model a basic 3-filaments wire. Although most results are coherent which each other, there is still optimization to do in order to find a computationally efficient approach to solve this problem and scale up to more realistic multi-filamentary wires.

OA7: Numerical techniques

Time: Thursday, 02/Jul/2015: 8:30am - 10:10am · *Location:* Room #0100

Session Chair: Anouar Belahcen

Session Chair: Jan Sykulski

ID: 281 / OA7: 1

Track 19

Topics: Numerical Techniques

Keywords: electromagnetics, finite element analysis, edge elements, tree-gauge

Partial Tree-Gauging of Second Order Edge Element Vector Potential Formulations

Oszkar Biro, Kurt Preis

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A technique to partially gauge vector potential formulations represented by second order edge basis functions is presented. The eliminated edges are locally defined and form a part of a tree of the graph defined by the finite element mesh. Hence, the curl of any vector potential spanned by the edges of the mesh can be represented as the curl a vector potential function supported by the retained edges. The resulting finite element equation system with a reduced number of degrees of freedom is well conditioned and, as illustrated by a numerical example, its iterative solution is significantly faster than that of the full system.

ID: 513 / OA7: 2

Track 20

Topics: Static and Quasi-Static Fields, Numerical Techniques

Keywords: Finite element analysis, Fourier series, interpolation, magnetostatics

A Defect Correction Scheme for the Accurate Evaluation of Magnetic Fields on Unstructured Grids

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In many low-frequency field simulations one is interested in a highly accurate evaluation of the field distribution in an observer region. We propose defect correction as an easy to implement and efficient alternative to higher order finite elements or hybrid approaches. Commonly splines have been used on structured grids for the reconstruction of the solution. Here, we introduce the use of radial basis functions on unstructured grids and study the convergence on the basis of an academic example.

ID: 361 / OA7: 3

Track 05

Topics: Numerical Techniques

Keywords: Finite element analysis, Method of moments, Eddy currents, Reduced order systems

Model-order reduction for the finite-element boundary-element simulation of eddy current problems including rigid body motion

Daniel Klis, Ortwin Farle, Romanus Dyczij-Edlinger

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A coupled finite-element boundary-element method for solving parametric models of eddy current problems is proposed. Affine approximation by the empirical interpolation method makes the numerical model accessible to projection-based parametric model-order reduction. The resulting low-dimensional system provides high evaluation speed at an accuracy comparable to that of the underlying discretization method.

ID: 10 / OA7: 4

Two Pages Short Version

Topics: Numerical Techniques

Keywords: Computational electromagnetics, finite element analysis, magnetostatics

Polygonal finite elements of arbitrary order

Tapabrata Mukherjee, Jon Webb

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Finite elements with the shape of arbitrary polygons have been previously described. Originally they were first order, i.e., able to represent exactly all polynomials of degree 1 in the space coordinates, but recently polygonal finite elements (PFEs) up to order 3 have been reported. Here we propose a general theory for generating PFEs of arbitrary order. Results for a wave problem and a magnetic field problem show the effectiveness of the elements up to order 5.

ID: 251 / OA7: 5

Track 11

Topics: Numerical Techniques

Keywords: Non-linear magnetostatic problem proper generalized decomposition, discrete empirical interpolation method

Application of the PGD and DEI methods to solve a Non-Linear Magnetostatic Problem coupled with the Circuit Equations

Thomas Henneron¹, stephane clenet²

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Among the model order reduction techniques, the Proper Generalized Decomposition (PGD) has shown its efficiency to solve static and quasistatic problems in the time domain. However, the introduction of non linearity due for example to ferromagnetic material has never been addressed. In this communication, the PGD technique combined with the Discrete Empirical Interpolation Method is applied to solve a non linear problem in magnetostatic coupled with the circuit equations.

PD1: Electromagnetic compatibility

Time: Thursday, 02/Jul/2015: 10:30am - 12:15pm · *Location:* Cafeteria

Session Chair: Jozsef Pavo

Session Chair: Charles William Trowbridge

ID: 152 / PD1: 1

Track 10

Topics: Electromagnetic Compatibility

Keywords: HVDC, Electromagnetic interference, Converter station, Thyristor valves, Wideband modeling

Electromagnetic Interference Prediction of $\pm 800\text{kV}$ UHVDC Converter Station

Haifeng Sun, Xiang Cui

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Electromagnetic disturbance (EMD) is generated during the processes of firing and turn-off of the valves in HVDC converter station. The EMD generated by valve operation is conducted through the wall bushings, along the buses in the AC yard and DC yard, to the overhead lines. The radiated interference is emitted from the major equipment into the adjacent space. Thus, wideband modeling of converter system is necessary to predict the characteristic of the electromagnetic interference (EMI) source. Methods of modeling and the equivalent circuits of the main equipments in HVDC converter stations are presented in this paper, including thyristor valves, converter transformer, smoothing reactor, filters and so on. The stray capacitances and inductance of the valves are calculated by different methods. Finally, the whole wideband model of the converter system is simulated by PSCAD/EMTDC. Based on the model, the characteristics of EMI under the condition of normal operation are calculated. Method of Images is used to calculate the radiated electromagnetic field around the converter station. In the end, the proposed method is verified by the comparison between calculated and measured.

ID: 153 / PD1: 2

Track 09

Topics: Electromagnetic Compatibility

Keywords: Antenna model, Electromagnetic radiation, IGBT, Method of moments, Source of disturbance.

Calculation of Electromagnetic Radiation of VSC-HVDC Converter System

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Voltage source converter (VSC)-based HVDC systems are of increasing prevalence due to the wide application of wind power, photovoltaic power, distributed generation, and smart grid technology. The paper presents a novel method for analyzing the radiated EMD (electromagnetic disturbance) of VSC-HVDC converter system considering its own structure and operational states, based on the experimental platform of VSC-HVDC converter system, located in the new energy laboratory of NCEPU. The mechanism of radiated EMD generated by converter valve is described. Simulation model of system operation is developed using PSCAD / EMTDC and sources of disturbance are got. With the antenna theory, antenna model of VSC-HVDC converter system is built. With electric dipole theory and RWG edge method, the radiated EMD produced by three-phase two-level converter is calculated by FEKO, a kind of MOM simulation software. Finally, the proposed method is verified by the comparison between calculated and measured.

ID: 165 / PD1: 3

Track 12

Topics: Static and Quasi-Static Fields, Electromagnetic Compatibility, Novel Computational Methods for Machines and Devices

Keywords: Eddy Currents, electromagnetic coupling, generalized partial element equivalent circuit (PEEC) method, integral equation, transmission lines.

A generalized PEEC Analysis of Inductive Coupling Phenomena in a Transmission Line Right-of-Way

Lucas Blattner Martinho^{1,2,3}, Jonathan Siau^{2,3,4}, Bertrand Bannwarth^{2,3}, Jean-Michel Guichon^{2,3}, Gérard Meunier^{2,3}, Olivier Chadebec^{2,3}, Viviane Cristine Silva¹

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A 3-D inductive coupling problem in a transmission line right-of-way is analysed with the generalized Partial Element Equivalent Circuit (PEEC) method. This new approach does not rely on the parallelism with the transmission line and allows the determination of the induced current density in underground objects at arbitrary positions and orientations.

ID: 180 / PD1: 4

Track 05

Topics: Electromagnetic Compatibility, Mathematical Modelling and Formulations

Keywords: Electromagnetic shielding, electromagnetic pulse, ferrite sheet, frequency-dependent complex permeability, slots

Analysis of Wideband Electromagnetic Field Penetration into a Multiply Slotted Metal Plate Coated with a Ferrite Sheet

Hyun Ho Park¹, Jong Hwa Kwon², Sang Il Kwak², Seungyoung Ahn³

¹The University of Suwon, Korea, Republic of (South Korea); ²Electronics and Telecommunications Research Institute (ETRI), Korea, Republic of (South Korea); ³KAIST, Korea, Republic of (South Korea); hhpark@suwon.ac.kr

This paper presents a rigorous analysis of electromagnetic field penetration into multiple slots on a metal plate loaded with a ferrite sheet having frequency-dependent complex permeability. The Fourier transform is used to represent the electromagnetic fields in the spectral domain and the mode matching technique is enforced to obtain a solution in rapidly converging series form, leading to numerically efficient results. Shielding effectiveness of electric and magnetic fields is investigated in terms of the geometrical parameters of multiple slots and ferrite sheet with frequency-dependent magnetic permeability.

ID: 272 / PD1: 5**Track 14***Topics:* Electromagnetic Compatibility, Optimization and Design*Keywords:* Finite Element Analysis, Electromagnetic Compatibility, Neural Networks, Genetic Algorithm, Optimization**Design Optimization a Wireless Power Transfer Link Considering Electromagnetic Compatibility****Abla Hariri, Ahmed Elsayed, Tarek Youssef, Osama Mohammed**Florida International University, United States of America; mohammed@fiu.edu

This paper proposes a method for the design optimization of a Wireless Power Transfer link (WPTL) for improved electromagnetic compatibility behavior. The method involves 3D Finite Element (3DFE) analysis and Artificial Neural Networks (ANN) to significantly reduce the computational time for the large number of iterations required for various designs. The 3DFE electromagnetic field solutions were utilized to predict the electromagnetic compatibility (EMC) of each design attained in the optimization search space. This is to achieve an electromagnetically compatible optimized design according to prevailing standards for these systems.

ID: 275 / PD1: 6**Track 20***Topics:* Wave Propagation, Electromagnetic Compatibility*Keywords:* AC Motors, electromagnetic compatibility, equivalent circuit model, parameter estimation**Extraction of High-Frequency Phase-to-Phase Coupling in AC Machine Using Mixed-Mode Network Parameters****Younggon Ryu, Ki Jin Han**Ulsan National Institute of Science and Technology, Korea, Republic of (South Korea); gonkure@unist.ac.kr

This paper proposes a method that can extract phase-to-phase transfer impedance of three-phase winding of an AC motor stator for high frequency characteristic. The phase-to-phase coupling parameters are obtained by calculating the relations between the terminal voltages and currents from single phase, common mode and differential mode. To verify the proposed method, the calculated input impedance is compared with the measurement result. By observation of the extracted phase-to-phase transfer impedance, a RLC equivalent circuit is constructed to estimate the components of phase-to-phase coupling noise. In addition, the antiresonance phenomenon of high frequency is discussed.

ID: 278 / PD1: 7**Track 10***Topics:* Electromagnetic Compatibility, Optimization and Design, Material Modelling*Keywords:* Absorbers, metamaterials, microwave, multi-band**An Array of Robust Multi-band Metamaterial Absorbers Using Octagonal Split Rings****Theofano Kollatou, Christos Antonopoulos**Aristotle University of Thessaloniki, Greece; tkollatou@gmail.com

The purpose of this paper is to present a set of efficient and robust metamaterial absorbers based on octagonal split ring resonant (O-SRR) periodic structures that can offer multi band absorption to practical applications for electromagnetic compatibility (EMC) engineers. The models of ultra-thin, compact O-SRR absorbers for operation at microwave frequencies are exhibiting very high absorptive regions. The idea is extended to broadband performance, where different setups are demonstrated and analyzed.

ID: 284 / PD1: 8**Track 11***Topics:* Electromagnetic Compatibility*Keywords:* Electromagnetic shielding, apertures, dipole**Shielding effectiveness of perforated screens through an inverse problem-based resolution****Lionel Pichon¹, Imed Briki², Jalel Ben Hajd Slama²**¹GeePs, CNRS, France; ²University of Sousse, Tunisie; pichon@lgep.supelec.fr

In this paper, we aim to evaluate the shielding effectiveness of perforated plane shields excited by a circular radiated loop in near-field. Our technique is based on an inverse problem using genetic algorithm and near-field measurements. Simulation is done using an electromagnetic simulation software tool, based on the method of moments. Using the approach proposed, an equivalent set of magnetic dipoles for each perforated metal screen is obtained. All results are compared with experimental values to check the validation. Such 2-D equivalent model can be used to avoid meshing screens in case a 3-D problem involving an enclosure with apertures.

ID: 309 / PD1: 9**Track 17***Topics:* Electromagnetic Compatibility, Numerical Techniques*Keywords:* Equivalent circuits, Finite element analysis, Impedance, Rail transportation**Fast Calculation the Ballastless Track Impedance of High Speed Railway Using FEM and PEEC Modeling Approach****Hanhua Zhang¹, Xuelong Du¹, Ji Qiao¹, Jun Zou¹, Jiansheng Yuan¹, Jin Yang², Zhixin Wang²**¹Tsinghua University, China, People's Republic of; ²Beijing National Railway Research & Design Institute of Signal & Communication; qiao13@mails.tsinghua.edu.cn

The ballastless track impedance of high speed railway is important for designing the railway signal system. In order to consider the influence of the reinforcement bar, a two-step decomposition approach is proposed. The basic idea is evaluating the track impedance without the reinforcement bar using 2D finite element method (FEM), and the incremental impedance due to the reinforcement bar is calculated by the partial element equivalent circuit (PEEC) model. The numerical examples show that the proposed approach can guarantee the accuracy and reduce the computational time, at least 20 times, compared to using 3D FEM directly.

ID: 311 / PD1: 10**Track 04***Topics:* Electromagnetic Compatibility, Numerical Techniques*Keywords:* Adaptive algorithms, Electromagnetic transients, Interpolation**Fast Evaluating the Lightning Horizontal Electric Field Using an Adaptive Hermite Interpolation in Frequency Domain****Boyuan Zhang¹, Xuelong Du¹, Ji Qiao¹, Jun Zou¹, Jiansheng Yuan¹, J.B. Lee², Munno Ju²**¹Tsinghua University, China, People's Republic of; ²Korea Electro-technology Research Institute, Korea;qiao13@mails.tsinghua.edu.cn

The horizontal electric field of a lightning channel, E_r , is the excitation for analyzing the field-to-transmission line problem. The $E_r(t)$ in time domain can be obtained via the Fourier transform technique, which requires calculating the $E_r(\omega)$, expressed in the form of general Sommerfeld integral at different frequencies repeatedly. In order to reduce the computing time, in this paper, an adaptive Hermite strategy is proposed to fit the E_r in a wide frequency range. The approach to calculate the E_r and its derivatives with respect to frequency is presented in the first place, and the adaptive algorithm for construct the interpolation model is outlined as well. The numerical examples show that the method proposed in this paper is at least 5 times faster than the one using the even sampling approach.

ID: 325 / PD1: 11**Track 09***Topics:* Education*Keywords:* Augmented reality technology, Electromagnetic field analysis, Visualization.**Immersive Real-time Visualization System of 3D Magnetic Field with Augmented Reality Technology for Education****Shinya Matsutomo¹, Kenta Mitsufuji², Shunsuke Miyazaki¹, So Noguchi³**¹National Institute of Technology, Niihama College; ²Osaka University; ³Hokkaido University; noguchi@ssi.ist.hokudai.ac.jp

We propose a new immersive real-time visualization system of 3D magnetic field utilizing Augmented Reality Technology for education in this paper. A real-time method of drawing flux lines in 3D space is newly developed for the proposed visualization system. It enables a user to easily observe and perceive a magnetic field generated by multiple sources (e.g. magnet and/or coil) in an augmented 3D space. Additionally, it permits the user to move the sources by own his/her hands and to observe the interfering magnetic field in real-time. As a result, the user can intuitively observe and understand the magnetic field even in 3D space.

ID: 374 / PD1: 12**Track 10***Topics:* Electromagnetic Compatibility, Mathematical Modelling and Formulations, Numerical Techniques*Keywords:* computational electromagnetics, integral equations, electromagnetic compatibility**A Mixed Surface Volume Integral Formulation for the Modeling of High Frequency Coreless Inductors****Zacharie De Greve⁴, Jonathan Siau^{1,2}, Gérard Meunier^{1,3}, Jean-Michel Guichon¹, Olivier Chadebec^{1,3}**¹University of Grenoble-Alpes, G2ELAB, F-38000 Grenoble, France; ²CEDRAT SA, F-38000 Grenoble, France; ³CNRS, G2ELAB, F-38000 Grenoble, France; ⁴University of Mons, B-7000 Mons, Belgium; zacharie.degreve@umons.ac.be

An original integral formulation dedicated to the high frequency modeling of electromagnetic systems without magnetic materials is presented. The total current density (i.e. conduction plus displacement currents) is approached by facet elements so that resistive, inductive and capacitive effects are all modeled. The method avoids moreover the volumic mesh of the conductors, which is too dense at high frequencies, due to the skin and proximity effects appearing e.g. in wound inductors. Surface impedance boundary conditions are employed to that end. The formulation is general and suitable for non simply connected domains. It is experimentally validated on a coreless wound inductor, using an impedance analyzer.

ID: 403 / PD1: 13**Track 13***Topics:* Electromagnetic Compatibility, Bio-Electromagnetic Computation*Keywords:* Charge while driving (CWD), optimization, fully electric vehicle, wireless power transfer (WPT), magnetic field exposure.**Optimization of a magnetic structure for wireless power transfer in charge while driving****Vincenzo Cirimele, Fabio Freschi, Luca Giaccone, Paolo Guglielmi, Maurizio Repetto**Politecnico di Torino, Dipartimento Energia, Corso Duca degli Abruzzi 24, 10129, Torino, IT; luca.giaccone@polito.it

The electromagnetic design of a wireless power transfer system focuses on the development of the magnetic structure of the coupled inductors. This paper deals with the design of novel magnetic structure for a light commercial vehicle in charge while driving. The design is carried out through an optimization procedure which aims to solve both EMC and exposure problems.

ID: 417 / PD1: 14**Track 08***Topics:* Electromagnetic Compatibility*Keywords:* Composite Transmission Line Tower, Conical Antenna, Direct Lightning Strokes, Finite Element Method**Modeling of Composite Transmission Tower under Direct Lightning Strokes Based on Electromagnetic Field Energy Principle****Youpeng Huangfu¹, Shuhong Wang¹, Xi Tao¹, Guolin Wang¹, Jian Wu²**¹Xi'an Jiaotong University, China, People's Republic of; ²State Grid Shaanxi Electric Power Research Institute 123 North Wenyi Road, Xi'an, China, People's Republic of; 708810661@qq.com

In this paper, an equivalent model for composite transmission line (TL) tower under direct lightning strokes based on electromagnetic field energy principle is comprehensively presented. The model consists of four parts: vertical grounding conductor, main legs, cross

arms and bracings. The impedances of the vertical grounding conductors and main legs of the composite tower are obtained combining the theory of conical antenna. The influence of composite material and bracings on the wave impedance are considered based on the electromagnetic field energy principle. The metal ground-wire cross arm is equivalent as a two parallel conductors. The composite phase-cross arm is regarded as a lumped capacitance which determined by using 3D Finite Element Method (FEM). An accurate model for extended grounding structure (EGS) of the tower base considering the soil ionization is used. The lightning overvoltage characteristic of the equivalent model is compared with the hybrid model in literature which verifies the validity of the model.

ID: 418 / PD1: 15

Track 20

Topics: Electromagnetic Compatibility, Mathematical Modelling and Formulations, Education

Keywords: computational electromagnetics, finite element analysis, electromagnetic compatibility, engineering education

Finite element models for studying the capacitive behaviour of wound components

Zacharie De Greve¹, Patrick Dular^{2,4}, Ruth Vazquez Sabariego³, Christophe Geuzaine⁴

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Finite element models of increasing accuracy are proposed for the study of the capacitive behaviour of wound magnetic components. Simple models, which are based on the classical assumption of a decoupling between electric and magnetic fields, are first described. Formulations which enable such a coupling are then presented. The models are tested on various coreless inductors, made of round conductors or copper sheets. The results are discussed and compared with experimental data measured with an impedance analyzer.

ID: 436 / PD1: 16

Track 10

Topics: Electromagnetic Compatibility

Keywords: Lightning, lightning magnetic fields, lightning protection system, reduced-scale model, truss bridge

Magnetic Fields inside Reduced-Scale Model of Truss Bridge by Direct Lightning: Simulations and Measurements

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This paper presents an evaluation of magnetic fields inside reduced-scale lightning protection systems (LPS) model of truss bridge resulting from direct lightning strikes. The method of coupled transmission line is employed to model the whole structure in three dimensions. The transient magnetic fields are calculated based on infinitesimal time-varying dipole theory and method of images. The computed results were verified versus some experimental results for the reduced-scale model with return conductors (RSRC). The reduced-scale model (2-m long, 1-m wide and about 0.5m high) was installed in high voltage laboratory. An impulse current generator injected a current in the roof of the truss bridge model, magnetic fields at critical points were measured.

ID: 621 / PD1: 17

Track 05

Topics: Electromagnetic Compatibility

Keywords: Electromagnetic Compatibility, mutual coupling, power electronic

New Measurement System of Magnetic Near-field with Multipolar Expansion Approach

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In EMC behavior of power electronic converters, it is important to predict near-field coupling between the complex components (e.g. in EMC filter). By using the components of near-field multipolar expansion of electromagnetic sources, the close magnetic coupling between two elements is determined from their equivalent model. In this paper a new measurement system, based on spherical harmonics and spatial filtering is proposed and studied. The sensor is a single coil moving along one axis, coupled with a rotatable mount for the measured source with two axes of rotation and . This simple system, which can be easily automated, allows building good accuracy models for complex sources. The impact of the uncertainties in position and orientation of the source and sensor are studied in order to determine the higher degree of the multipolar expansion that can be characterized. Taken into account these uncertainties and the expected precision of the reconstructed source, strategies of measurement minimizing the number of measurements are compared.

ID: 625 / PD1: 18

Track 02

Topics: Electromagnetic Compatibility

Keywords: Maxwell's equations, Discontinuous Galerkin Method, Hexahedral meshes, CFL condition, Wire fault modeling, Reflectometry diagnosis

Time domain modeling of soft faults in wiring system by a nodal Discontinuous Galerkin Method with high-order hexahedral meshes

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A time domain nodal discontinuous Galerkin method is used to solve Maxwell equations and simulate reflectometry responses of soft faults. In this paper shielding defects of coaxial cables or other shielded lines are considered. Hexahedral high order elements are used for meshing. They allow to avoid bulky meshes compared to tetrahedral elements. A gaussian pulse is injected on the faulty line. The reflectogram of the line containing the chafing soft defect is obtained and parameters such as the reflection coefficient or the characteristic impedance of the fault are computed. These numerical values are compared to those obtained in experimental investigations. The experimental impedances estimated using a classical transmission matrix method are in very good agreement with those obtained by three-dimensional modeling.

PD2: Optimization and design 3

Time: Thursday, 02/Jul/2015: 10:30am - 12:15pm · *Location:* Lounge

Session Chair: Luiz Lebensztajn

Session Chair: Guangzheng Ni

ID: 106 / PD2: 1

Track 07

Topics: Optimization and Design

Keywords: Electromagnetic optimization, Metaheuristics, Social-spider optimization.

Modified Social-Spider Optimization Algorithm Applied to Electromagnetic Optimization

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Social spider optimization (SSO) is a new nature-inspired algorithm of the swarm intelligence field to global optimization applications, based on the simulation of cooperative behavior of social-spiders. To enhance the performance of the standard SSO, a modified SSO (MSSO) approach based on beta distribution was proposed in this paper. In order to verify the performance of the MSSO, tests using Loney's solenoid benchmark and a brushless DC (Direct Current) motor benchmark are realized to evaluate the effectiveness of the SSO and the proposed MSSO. Simulation results and comparisons with the SSO demonstrated that the performance of the MSSO approach is promising in electromagnetics optimization.

ID: 129 / PD2: 2

Track 17

Topics: Optimization and Design

Keywords: Actuator design, magnetic shape memory alloys, non-homogeneous permeability, smart materials

Effects of Varying Permeability of Magnetic Shape Memory (MSM) Alloys on Design and Performance of Actuators

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Magnetic Shape Memory (MSM) alloys, which change shape under magnetic field, have enormous potential to be used in actuators, sensors and other electrical devices due to their "smart" properties and large strain output that can be controlled magnetically. Maximum magnetic field induced strain varies from 6 to 12% of the MSM element's length depending on its microstructure. The dependence of MSM magnetization and resistance on strain allows designing self-sensing actuators. At the same time, variations of MSM properties with strain complicate their performance modelling and analysis. In this paper we show how varying MSM permeability affects the performance of MSM actuators. The effects of non-homogeneous MSM microstructure on the applied field is analysed by modelling and computation of magnetic field distribution using the finite element method (FEM). This allows design optimization of actuators in terms of geometric parameters and power consumption.

ID: 243 / PD2: 3

Track 09

Topics: Optimization and Design

Keywords: Permanent magnet machines, AC machines, Sensorless control, Electric vehicles

Design of Saliency-Based Sensorless Controlled IPMSM with Concentrated Winding for EV Traction

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This paper investigates the influence of the geometry design parameters of saliency-based sensorless-controlled interior permanent magnet synchronous motors (IPMSMs) with concentrated winding on the sensorless drive feasibility. To evaluate the sensorless controllability of the motors, two different methods to estimate rotor position error are proposed. By using the methods, the geometry design parameters in the stator are analyzed to figure out which ones have a positive effect on sensorless drive. Based on the analysis result, in the full paper, a final model applied with a selected design parameter is going to be proposed for electric vehicle (EV) traction application. The validity of the proposed estimation methods and the design results will be verified by the experiments.

ID: 261 / PD2: 4

Track 15

Topics: Optimization and Design

Keywords: Carter's coefficient, field form factor, hydro electrical generator, magnetic flux density waveform, salient pole machine, air gap magnetic flux density waveform

Numerical Computation of Hydro Electrical Generators Field Form Coefficients

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The field form factor and Carter's coefficient are the key parameters in the optimization process of large electrical machines. These coefficients are usually computed by an analytical method with many assumptions. In this paper, a numerical approach based on the finite element analysis (FEA) is proposed to compute these parameters achieving better accuracy. The advantage of this procedure is that it allows taking into account the whole harmonic content. The proposed approach is first described and applied to evaluate these two coefficients form in case of existing large hydro electrical generator and then compared to that obtained using analytical methods in order to evaluate the accuracy of the latter.

ID: 266 / PD2: 5**Track 13***Topics:* Optimization and Design*Keywords:* DE, multi-objective optimization, QPSO, tabu search method.**A Hybridized Vector Optimal Algorithm for Multiobjective Designs of Inverse Problems****Guanzhong Hu, Shiyong Yang, Yuling Li, Shafi Ullah Khan**Zhejiang University, China, People's Republic of; shiyongyang@yahoo.com

Problem with multiple objectives is a natural fashion in most disciplines of the real world, and multi-objective evolutionary algorithm is a technique which has a challenge of achieving a series of best solutions with respect to fitness and spread. In this regard, it is essential to keep the balance of local and global search abilities. Quantum-behaved Particle Swarm Optimization (QPSO) is a population-based swarm intelligence algorithm, and Differential Evolutionary (DE) is another simple population based stochastic search method for global optimization with real valued parameters. Although the two techniques have been successfully employed to solve a wide range of problems, they also suffer from the premature convergence and the lack of diversity in the latter searching stages. This is probably due to the insufficient dimensional searching strength, especially for multi-objective optimization problems with many decision parameters. In this study, a new multi-objective non-dominated optimization methodology combining QPSO, DE and Tabu search algorithm (QPSO-DET) is proposed to guarantee the balance between the local and global searches. The performances of the proposed QPSO-DET are compared with those of other two widely recognized vector optimizers using different case studies.

ID: 333 / PD2: 6**Track 13***Topics:* Optimization and Design*Keywords:* Level set, Robustness, Topology optimization, Uncertainty**Level set based robust topology optimization of electromagnetic system under loading uncertainty****In-Han Ga¹, Jaeyub Hyun², Hyung-Woo Kim², Semyung Wang²**¹Hanwha Corporation, Korea, Republic of (South Korea); ²Gwangju Institute of Science and Technology, Korea, Republic of (South Korea); ih.ga@hanwha.com

This paper proposes robust topology optimization (RTO) of electromagnetic (EM) design problem for uncertain loads (UL) using level set (LS) method. Maximization of expected value and variance of EM energy is adopted for objective function to obtain robust result under uncertain coercive loadings. For normally distributed stochastic conditions, the problem for UL is equivalent to multiple load case problems. Therefore analytically derived shape sensitivity is efficiently calculated and computation cost increases linearly with the number of UL. The suggested method is implemented to c-core actuator problem considering uncertainty of coercive force.

ID: 395 / PD2: 7**Track 14***Topics:* Optimization and Design*Keywords:* Benchmark problem, fitting accuracy, Kriging surrogate model, TEAM 25 problems**A Novel Adaptive Dynamic Taylor Kriging and Its Application to Optimal Design of Electromagnetic Devices****Bin Xia¹, Tae-Woong Lee¹, Kyun Choi², Chang-seop Koh¹**¹Chungbuk National University, Korea, Republic of (South Korea); ²Kangwon National University, Korea, Republic of (South Korea); tiandixiabn@chungbuk.ac.kr

An adaptive dynamic Taylor Kriging (ADTK) is developed and combined with the particle swarm optimization algorithm to get a numerically efficient optimization strategy. In the ADTK, the optimal basis function set is dynamically selected so that the generated surrogate model may have better accuracy. An adaptive sampling method about how many sampling points are required for a specific fitting accuracy is proposed. The proposed approach was tested on the analytic function and the TEAM 25 problem.

ID: 592 / PD2: 8**Track 13***Topics:* Static and Quasi-Static Fields, Optimization and Design, Numerical Techniques, Novel Computational Methods for Machines and Devices*Keywords:* Finite element analysis, optimization, permanent magnet machines, robustness**Robust Optimization and Uncertainty Quantification of a Permanent Magnet Synchronous Motor's Geometry****Oliver Lass¹, Stefan Ulbrich¹, Zeger Bontinck^{2,3}, Herbert De Gersem³, Sebastian Schöps^{2,3}**¹Chair of Nonlinear Optimization, Department of Mathematics, Technische Universitaet Darmstadt, Germany; ²Graduate School of Computational Engineering, Technische Universitaet Darmstadt, Germany; ³Institut fuer Theorie Elektromagnetischer Felder, Technische Universitaet Darmstadt, Germany; degersem@temf.tu-darmstadt.de

The volume and position of permanent magnet material in a synchronous machine are optimized. The paper proposes a robust optimization process which also accounts for geometric uncertainties. The results are also verified by stochastic collocation and show a slightly worse optimum, which is however robust against manufacturing tolerances.

ID: 708 / PD2: 9**Two Pages Short Version***Topics:* Optimization and Design*Keywords:* Bayesian regularization, finite-element analysis, genetic algorithm, multi-objective optimization, neural networks, surrogate modelling, Synchronous Reluctance Machines.**A Computationally Efficient Algorithm for Rotor Design Optimization of Synchronous Reluctance Machines****Mohammad Mohammadi, Tanvir Rahman, Rodrigo Silva, Min Li, David Lowther**McGill University, Canada; david.lowther@mcgill.ca

A computationally efficient algorithm for rotor design optimization of Synchronous Reluctance Machines (SynRM) has been proposed. A mixed integer design space of rotor pole numbers and single barrier rotor geometry was considered to develop a generalizable

algorithm for carrying out multi-objective design and optimization of SynRMs. By using 2D FEA time stepping simulations, two objective values per sampled design were generated: average torque and torque ripple. Non-linear regression analysis using the Bayesian Regularization Backpropagation Neural Network (BRNN) was used to train surrogate models for the two design objectives. A convergence criterion of 20 neurons for the hidden layer size was observed per objective. The resulting Response Surface (RS) models were then used to calculate an objective space Pareto front through Genetic Algorithm (GA) optimization.

ID: 267 / PD2: 10

Track 14

Topics: Optimization and Design

Keywords: Magnetic actuator, ON/OFF method, topology optimization.

A Methodology for Topology Optimization Using ON/OFF Method and its Application to Magnetic Actuator Designs

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The topology optimization of electromagnetic devices is a new emerging technique, and very attractive for a designer since an initial optimal design can be obtained beforehand. In this paper, a methodology using ON/OFF method is introduced to obtain the optimal topology of a magnetic actuator for maximizing the force in a specific direction. The methodology introduces an annealing mechanism for refinement and efficient topology optimizations. Using finite element methods, the magnetic field is computed and the magnetic force is derived. To implement the ON/OFF method, the sensitivity of the objective function is computed according to the magnetic permeability perturbation on each element in the design domain. As a result, the optimal topology of the design domain is obtained and a significant improvement in performances is observed.

ID: 264 / PD2: 11

Track 13

Topics: Optimization and Design

Keywords: Dynamic inertia weight, dynamic learning factors, mutation operator, PSO.

A Modified Particle Swarm Optimization Algorithm for Global Optimizations of Inverse problems

Shafi Ullah Khan, Shiyong Yang, Luyu Wang, Lei Lei Liu

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Particle Swarm Optimization (PSO) is a population based stochastic search algorithm inspired from the natural behavior of bird flocking or fish schooling. Due to its easiness in numerical implantations, PSO is used to solve a wide range of inverse problems. However, a PSO is often trapped into local optima while dealing with complex and real world problems. To tackle this problem, a new modified PSO is presented by introducing a mutation mechanism and using dynamic algorithm parameters. The experimental results on different case studies show that the proposed PSO obtain the best results among the tested algorithms.

ID: 114 / PD2: 12

Track 01

Topics: Optimization and Design

Keywords: Axial flux permanent magnet synchronous motor, kriging, multi-objective, surrogate model.

A New Surrogate Assisted Multi-Objective Optimization Algorithm for an Axial Flux Permanent Magnet Synchronous Motor Design

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In this paper, a new surrogate assisted multi-objective optimization (SAMOO) algorithm is presented to optimize an axial flux permanent magnet synchronous motor (AFPMSM) design. The proposed algorithm is a multi-objective algorithm (MOO) that can both maximize the torque amplitude and minimize the torque ripple to improve the power transmission efficiency and stability of an AFPMSM control considering various design variables. While the conventional MOO algorithms have a serious problem of requiring too many function calls especially considering many design variables, the proposed algorithm can make an accurate and a well-distributed Pareto front set with fewer function evaluations. The superiority of the proposed algorithm is verified by comparing with conventional MOO algorithms. Finally, the proposed algorithm is applied to an optimal design process of an AFPMSM.

ID: 573 / PD2: 13

Track 13

Topics: Optimization and Design

Keywords: Optimization, Particle swarm optimization, Evolutionary computation

Firefly Algorithm for Finding Global Optimal Shapes of Electromagnetic Devices

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Many real world optimization problems have to be treated as multi-objective optimization problems. Relying on scalar optimization methods, a suitable objective function taking all objectives into account has to be defined. Besides that, in the feasible region of the trial variables a remarkable number of local solutions could be expected, one of them resulting in the best value of the chosen objective function. Therefore, a scalar optimization strategy should be able to end up in the best of all possible solutions (in the given search space) and additionally detect as many local solutions as possible. The Firefly Algorithm (FFA), one of many metaheuristic optimization methods, mimics the natural behaviour of fireflies, which use a kind of flashing light to communicate with other members of their species. The information conveyed can be either the message about the quality of food supply, but it can also be a

notice about possible threats. A Clustered Firefly Algorithm will be applied to detect as many local solutions as possible on its way to the best solution in the given search space and its performance will be compared to a Niching Higher Order Evolution Strategy (NES).

ID: 31 / PD2: 14

Track 07

Topics: Optimization and Design, Mathematical Modelling and Formulations

Keywords: Nondestructive testing, interpolation, database, metamodeling, sparse grid

Sparse grid surrogate models for electromagnetic problems with many parameters

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A sparse grid surrogate model is proposed to reduce the time-consumption involved by precise electromagnetic simulators. Though sparse grids have already been used in many other domains, such an electromagnetic application appears to be original. The method can treat a high number of independent parameters that are intractable for many other techniques due to the "curse of dimensionality". The capabilities are illustrated via an example drawn from electromagnetic nondestructive evaluation.

ID: 588 / PD2: 15

Track 01

Topics: Optimization and Design

Keywords: genetic algorithms, design optimization, finite element analysis, electromagnetic fields, electromagnetic forces, machine components, valve

Acceleration of evolution-based algorithms by relation preconditioning of optimization parameters

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A modified genetic algorithm is proposed for optimization of low-dimensional systems of mathematical models described by partial differential equations. The paper explains its principle, benefits and illustrates its utilization on the shape optimization of the plunger of a bearingless electromagnetic actuator, whose goal is to maximize the force acting on the plunger during its operation. The algorithm is implemented in the framework OptiLab that represents a part of application Agros2D developed by the authors.

PD3: Numerical techniques 3

Time: Thursday, 02/Jul/2015: 10:30am - 12:15pm · *Location:* Lounge

Session Chair: Alain Bossavit

Session Chair: Wolfgang M. Rucker

ID: 91 / PD3: 1

Track 07

Topics: Numerical Techniques

Keywords: Electromagnetics, optimization, reliability theory, robustness

Enriched Serial-Loop Optimization Method for Efficient Reliability-Based Electromagnetic Designs in the Presence of Uncertainties

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An enriched serial-loop method for reliability-based design optimization is presented to substantially enhance computational efficiency as well as numerical accuracy when applied to electromagnetic design problems in the presence of uncertainties. In the method, two improvements are made over the original serial-loop optimization method, which employs a serial of cycles of equivalent deterministic optimization and reliability analysis. One is a feasibility check technique for probabilistic constraints conducted only after the first design cycle. It can identify inactive constraints, which need not be taken into account during the next design cycles. The other is a reliability improvement scheme for slightly violated probabilistic constraints performed at the end of iterative design cycles. When an optimum point is unsatisfactory to all probabilistic constraint conditions given, the design point is shifted toward a feasible design region by utilizing probabilistic information obtained. Finally, the TEAM Workshop Problem 22 is tested to compare the proposed method with the original one from a numerical efficiency and accuracy point of view.

ID: 104 / PD3: 2

Track 09

Topics: Numerical Techniques, Material Modelling

Keywords: Magnetic losses, magnetic hysteresis, eddy currents, finite element analysis, electromagnetic fields

Improvement of Convergence Characteristics of 1-D Dynamic Magnetic Field Analysis with Hysteresis for Iron Loss Estimation

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In the previous study on precise computation methods of magnetic loss, it has been shown that one-dimensional dynamic magnetic field analysis with a hysteresis in post-processing is effective. However, there is a problem that the hysteresis makes the convergence of nonlinear iteration unstable. So this paper proposes a stabilization method for one-dimensional dynamic magnetic field analysis with a hysteresis. The proposed method is characterized as approach of improving the initial value and the step size in Newton-Raphson method (NR). Results of the study, it exhibited this method can improve the convergence characteristic of nonlinear iteration and has the robustness for frequency. Therefore it can be expected we keep the stable convergence for harmonic magnetic flux in electric motor.

ID: 155 / PD3: 3

Track 04

Topics: Numerical Techniques

Keywords: Finite Element Method (FEM), Model Order Reduction (MOR), Proper Orthogonal Decomposition (POD), Error estimation

Reduction of a Finite Element Parametric Model using Adaptive POD methods

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Model Order Reduction (MOR) methods enable reduction of the computation time when dealing with parametrized numerical models. Among these methods, the Proper Orthogonal Decomposition (POD) method seems to be a good candidate because of its simplicity and its accuracy. However, the accuracy strongly depends on the choice the parameter set chosen to construct the reduced basis. In this communication, we propose three different procedures for an adaptive construction of the parameter set. The accuracy of the three methods is compared on a 2D Finite Element model example in magnetostatics.

ID: 169 / PD3: 4

Track 18

Topics: Static and Quasi-Static Fields, Numerical Techniques

Keywords: difference magnetic field, double layer charge, integral equations, magnetic shielding, magnetostatics

Magnetostatic Shield Analysis by Double Layer Charge Formulation Using Difference Field Concept

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This paper proposes novel accuracy improvement and high speeding techniques for double layer charge (DLC) formulation in shielding problems. Although the DLC formulation has advantages over the direct methods from the viewpoint of computational cost, the calculation accuracy can be worse because of cancellation errors. In order to improve the accuracy, we apply a new technique based on difference field concept to the DLC formulation. In addition, we succeed in shortening a calculation time by simplifying the DLC formulation. Numerical results which verify the effectiveness of the proposed methods are presented.

ID: 174 / PD3: 5

Track 06

Topics: Numerical Techniques

Keywords: Permanent magnet machines, rotating machine, finite element analysis, reduced order systems, computational efficiency

Fast Finite Element Analysis of IPM Motors Using Block Model Order Reduction

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This paper presents fast finite element analysis of IPM motors using model order reduction (MOR) based on the proper orthogonal decomposition (POD). It is known that one needs long computational time for POD-based MOR applied to moving objects for which many basis vectors are necessary. In the present block MOR, the domain is subdivided into several blocks in each of which the basis vectors are constructed from snapshot solutions. The computational time of block MOR is shorter than that of the conventional MOR while accuracy of both methods are almost the same.

ID: 205 / PD3: 6

Track 13

Topics: Optimization and Design, Numerical Techniques

Keywords: Finite element, mesh deformation, optimal shape design, three-dimensional magnetic field

A Fast Remesh-free Mesh Deformation Method Based on Radial Basis Function Interpolation and Its Application to Optimal Design of Electromagnetic Devices

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Optimal shape design of electromagnetic (EM) devices using finite element parameter sweeping analysis is becoming a routine procedure today. In the optimal design process, different meshes for different device shapes are required for subsequent finite element computations in order to obtain the objective function values from the field solution. Traditional full or partial remeshing methods usually consume excessive computing time when generating these finite element meshes, especially for three-dimensional (3-D) problems. The proposed remesh-free method being reported is based on a radial basis function (RBF) interpolation technique, which can save the mesh-regeneration time and greatly accelerate the optimal design process. The proposed method needs a fine finite element mesh which can be generated by any external meshing software. An algorithm to find the boundary nodes located on the geometry outlines or material interfaces is proposed to prescribe the source displacement vectors there. A RBF interpolation function for the boundary nodal motion is then being solved and this process needs to be done once and only once. If the geometry is updated for new design parameters, the displacement vectors for all the nodes can be interpolated from the reconstructed RBF and hence the proposed mesh deformation method is remesh-free. The method can be applied to both two-dimensional (2-D) and 3-D problems. 2-D and 3-D numerical examples are given to showcase the effectiveness of the proposed method.

ID: 209 / PD3: 7

Track 20

Topics: Numerical Techniques

Keywords: Electric and magnetic field integral equations, electromagnetic scattering by bodies of revolution, Galerkin technique, method of moments

Evaluation of Electromagnetic Scattering by Conducting Bodies of Revolution with Discontinuous Currents

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In this work the electromagnetic radiation from conducting bodies of revolution with discontinuities in the equivalent surface currents is investigated. The simulations are based on the Combined Field Integral Equation evaluated by the Method of Moments. A strategy for implementing an integral equation formulation without restrictions over the testing functions is presented. The procedure is applied in the analysis of the radiation from a circular horn antenna and numerical results are compared with experimental data.

ID: 238 / PD3: 8

Track 20

Topics: Numerical Techniques

Keywords: Approximation algorithms, Linear systems, Iterative algorithms, Numerical analysis, Electrostatic processes.

A Variable Preconditioning of Krylov Subspace Methods for Hierarchical Matrices with Adaptive Cross Approximation

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Krylov subspace methods to solve linear systems whose coefficient matrix is represented by an hierarchical matrix are discussed. We propose a precondition technique using a part of the original hierarchical matrix in order to accelerate the convergence of the Krylov subspace methods. The proposed precondition technique is based on the assumption that sub-matrices on the original hierarchical matrix are approximated by using the adaptive cross approximation or variants thereof. The performance of Krylov subspace methods with the proposed precondition technique are examined through numerical experiments on an electrostatic field analysis.

ID: 259 / PD3: 9

Track 10

Topics: Numerical Techniques

Keywords: meshless methods, natural element method, polygonal elements, vector interpolation

Vector Interpolation on Natural Element Method

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Electromagnetic simulation often requires vector edge-based shape functions. In a Finite Element Method (FEM) context, vector shape functions are designed for keeping the tangential continuities and normal discontinuities between elements, which corresponds to the physical nature of electromagnetic fields. However, in the meshless methods context, the construction of vector shape functions is not direct and very little work has been published on vector meshless interpolation. This work is a first proposal of a NEM-based vector interpolation for polygonal cells. Fundamental results of the developed approach are demonstrated.

ID: 427 / PD3: 10

Track 10

Topics: Numerical Techniques, Novel Computational Methods for Machines and Devices

Keywords: approximate methods, finite element analysis, iterative methods, power transformers, sparse matrices

A Near Zone Preconditioner with Sparse Approximate Inverses for Solving Finite Element Equations

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A physically motivated near zone preconditioner is presented for solving the equations obtained from finite element method. Different from common sparse approximate inverse (SPA) preconditioner, the proposed one gives the sparsity pattern based on a physical approximation. And its sparseness can be adjusted in different applications. The process of the algorithm needs low memory and CPU time, and is inherently parallel. The preconditioner in conjunction with conjugate gradient method is used to calculate the electrical fields in a power transformer. And this application demonstrates the effectiveness of the approach.

ID: 594 / PD3: 11

Track 19

Topics: Numerical Techniques

Keywords: Convergence, finite element method, iterative methods, parallel processing, sparse matrices

Parallelization of Preconditioned MRTR Method Combined with Block-multicolor Ordering Supported by Level Structure Arising in RCM Ordering

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The performance of preconditioned MRTR method using multicolor (MC) ordering has been demonstrated on various symmetric linear systems derived from 3-D FEM. Even if the degree of parallelization is increased, the convergence characteristic of preconditioned MRTR with MC does not deteriorate. However, the elapsed time using MC is longer than that using block preconditioner with RCM ordering because the cache hit deteriorate owing to increase in bandwidth. To realize further reduction of elapsed time, the block-multicolor (BMC) ordering based on level structure arising in RCM ordering is proposed. The validity of proposed method is shown in comparison to conventional block preconditioner combined with the traditional orderings.

ID: 695 / PD3: 12

Two Pages Short Version

Topics: Numerical Techniques

Keywords: Anisotropic media, mixed finite-element time-domain (FETD), high-order perfectly matched layer (PML).

Second-Order Uniaxial Perfectly Matched Layer for Finite-Element Time-Domain Methods

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There has always been a compromise between the regular and complex frequency shifted (CFS) perfectly matched layers (PMLs) in simulation of open-region problems in electromagnetics. They fail to provide accurate results when evanescent and low-frequency propagating waves exist in the problem. A PML with metrics composed of multiple poles, i.e., high-order PML, has shown great performance in such situations. In this paper, we extend the application of the second-order PML to both mixed E - B finite element time-domain (FETD) and vector wave equation (VWE) FETD methods. In order to have an efficient and easier-to-implement formulation, the Möbius transformation technique is employed in discretization of the PML metrics. A numerical result is provided to demonstrate the validity of the formulation.

ID: 698 / PD3: 13

Two Pages Short Version

Topics: Numerical Techniques

Keywords: Finite Element Method, iterative methods, Krylov subspace methods, Gaussian Belief Propagation.

Acceleration of the Finite Element Gaussian Belief Propagation Solver Using Minimum Residual Techniques

Yousef El-Kurdi¹, David Fernández^{1,2}, Warren J. Gross¹, Dennis D Giannacopoulos¹

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The Finite Element Gaussian Belief Propagation method (FGaBP) introduced recently provides a powerful parallel alternative to conventional Finite Element Method (FEM) solvers. In this work we accelerate the FGaBP convergence by combining it with two methods based on residual minimization techniques. Numerical results show considerable reductions in the total number of operations while maintaining the scalability features of FGaBP.

PD4: Wave propagation 2

Time: Thursday, 02/Jul/2015: 1:45pm - 3:25pm · *Location:* Cafeteria

Session Chair: Yasushi Kanai

Session Chair: Ruben Specogna

ID: 63 / PD4: 1

Track 11

Topics: Wave Propagation

Keywords: Computational electromagnetics, method of moments, compression algorithm

An Efficient Compression Representation of Adaptive Cross-approximation for Analysis Microstrip Problems

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In order to efficiently solve large dense complex linear systems arising from electric field integral equations (EFIE) formulation of electromagnetic problems, the adaptive cross-approximation (ACA) has been used to accelerate the matrix-vector product (MVP) operations. This paper presents an efficient representation of impedance matrix of ACA for microstrip problems. First, a series of basis matrices at lowest level are constructed by singular value decomposition (SVD). Based on the basis matrices, the far-field interaction parts of impedance matrix can be represented by multiplication of three sparse matrices in recursive manner. Numerical experiments demonstrate that our efficient representation of ACA algorithm outperforms original ACA in terms of memory requirement of far-field interactions and the time per MVP operation.

ID: 219 / PD4: 2

Track 19

Topics: Wave Propagation

Keywords: Millimeter wave propagation, Data communication, Datacenter, Data-server, Server-rack, finite difference time domain (FDTD) method, electromagnetic shielding

FDTD Analysis of Millimeter Wave Data Communication between Data-servers in Server-rack

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In a large scale datacenter, it is pointed out that a considerable amount of cable connections between data-servers for data communication occupies large space inside a server-rack, and causes reduction of cooling performance which leads to heavy electric power consumption. To solve this problem, it is considered to replace the wired communication by a millimeter wave wireless communication. For the millimeter wave communication, it is required that the millimeter wave has to be isolated inside the server-rack to keep information security, at the same time, the server-rack wall has to have sufficient amount of aperture to maintain cooling performance by airflow. Accordingly the server-rack back door has to have mesh structure to satisfy these conditions. To find out the appropriate shielding mesh specification, this paper presents a design study of the server-rack back door structure made by the shielding mesh using the finite difference time domain (FDTD) method numerical simulation.

ID: 230 / PD4: 3

Track 05

Topics: Wave Propagation, Numerical Techniques

Keywords: 60 GHz wireless communication, indoor channel model, Time-Domain Geometric-Optics

60-GHz Indoor Propagation with Time-Domain Geometric-Optics

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Compared with 2.4 GHz and 5GHz, 60 GHz has the potential of high speed communication. In this paper, 60 GHz indoor propagation is studied with the Time-Domain Geometric-Optics (TDGO) method. Compared with full wave numerical methods of electromagnetic simulation such as the finite difference time domain (FDTD), the TDGO takes less operating time. For the wide band communication, the TDGO is more accurate than geometric optics (GO) in frequency domain.

ID: 273 / PD4: 4

Track 13

Topics: Optimization and Design, Numerical Techniques

Keywords: EFG, electromagnetic scattering, computational electromagnetics, meshless methods, optimization methods

2D Electromagnetic Scattering Solution Using EFG Meshless Method and Differential Evolution Optimization Algorithm

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This paper presents the use of the Differential Evolution algorithm as an optimization method for 2D electromagnetic scattering problem solved by interpolating Element-Free Galerkin (EFG) meshless method. It is considered the TMz plane wave scattering by a z-infinite dielectric cylinder. The numeric and analytic solutions are compared by using the L2 norm error. The Differential Evolution method is applied in order to find good sets of interpolating EFG parameters that minimize the L2 norm error.

ID: 318 / PD4: 5

Track 19

Topics: Wave Propagation, Software Methodology

Keywords: Finite-element methods, open boundary problem, Helmholtz equation, non-linear optimization

Improved Absorbing Boundary Conditions for Two-dimensional Electromagnetic Finite Elements

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Improved absorbing boundary conditions (IABC) for two-dimensional high frequency electromagnetic finite elements have been proposed. The IABC method approximates unbounded space as series of isotropic cylindrical shells so as to emulate open boundaries without the need for additional code to any finite element solver. Previous work addressed applications of this technique to magnetostatic and electrostatic problems. This present work extends the method to two-dimensional high-frequency electromagnetic propagation problems.

ID: 323 / PD4: 6

Track 20

Topics: Wave Propagation

Keywords: Electromagnetic propagation, Miter Bend, Numerical simulation, FDTD, Drude model.

Electromagnetic Wave Propagation Simulation in Corrugated Waveguide with Miter Bend by FDTD: Influence of Induced Current Density

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The optimal corrugated grooves in miter bend are verified by electromagnetic wave propagation simulation using Finite-Difference Time-Domain (FDTD) method, and the effect of induced current density in the waveguide wall is implemented by Drude model. From the simulation results, after bending electromagnetic wave at miter bend, the transfer mode was distorted by reflection at the miter bend mirror. After transmitting in the corrugated waveguide, the transfer mode that is distorted was transitioned to the eigenmode. In addition, the transmission efficiency strongly depends on the corrugated grooves. The parameters of the structure of the corrugated grooves that are determined experimentally were high transmission efficiency by the simulation.

ID: 484 / PD4: 7

Track 20

Topics: Wave Propagation, Numerical Techniques

Keywords: Electromagnetic propagation, error correction, finite-difference methods, numerical stability.

Efficient Integration of High-Order Stencils into the ADI-FDTD Method

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Incorporating standard high-order spatial approximations in the alternating-direction-implicit (ADI) finite-difference time-domain (FDTD) method does not suffice for accuracy improvement, as these operators are capable of reducing spatial errors only. We herein propose an alternative design procedure, which guarantees finite-difference expressions that minimize the overall space-time flaws. In essence, error formulas are derived from the individual implicit equations, when the ADI update is treated as a single-step process. Then, efficient spatial expressions are extracted via proper manipulations of these formulas that apply error-controlling concepts.

ID: 518 / PD4: 8

Track 19

Topics: Numerical Techniques

Keywords: Ultra Weak Variational Formulation, Generalized Finite Element Method, Plane Wave Basis, Condition Number.

Comparative Analysis of the Generalized Finite Element Method and the Ultra Weak Variational Formulation Approaches to Solve Electromagnetic Scattering Problems

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This paper presents a comparative analysis of the Ultra Weak Variational Formulation (UWVF) and the Generalized Finite Element Method (GFEM) approaches to compute the solution field generated by the scattering of an incident plane wave by a PEC obstacle. The aim is to show how the specific features of each approach can be used to improve the approximated solution. The results are supported by numerical experiments and case studies.

ID: 629 / PD4: 9

Track 20

Topics: Wave Propagation, Electromagnetic Compatibility, Mathematical Modelling and Formulations, Numerical Techniques

Keywords: Computational electromagnetics, electromagnetic metamaterials, integral equations, microstrip antennas, optical cloaking

Consistent Integral Equation Modeling of Cloaking Planar Microstrip Antennas

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In this paper, an efficient integral equation methodology is developed in order to compute the response and scattering characteristics of cloaked two-dimensional planar microstrip antennas. The featured technique combines the expressions of the Green's function for the strip-free structure, the decomposition of the strip into cylindrical thin wires, and the radiation integral algorithm for the evaluation of the scattered field. In essence, the desired cloaking and low-profile operation of the receiving antenna are achieved by overlaying a superstrate slab atop of the antenna. To this objective, the electric and magnetic constitutive parameters together with the thickness of

the slab are appropriately determined so that an optimally-reduced scattering performance is obtained, as verified by the corresponding computational results.

ID: 651 / PD4: 10

Track 15

Topics: Optimization and Design

Keywords: Circular Patch, Metamaterial Substrate, Microstrip Patch Antenna, Parameters Optimization

Circular Patch Antenna Inspired by the Use of Two Metamaterial Substrate Layers

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Performance optimization has been achieved for a circular patch antenna filled with two metamaterial layers. The first layer of metamaterial is obtained through complementary split-ring resonators patterned on the ground plane and the second metamaterial layer is patterned by small crossed strips located between two thin layers of the substrate. The proposed new model features three resonant frequencies and is observed an increased gain in the device. The results are provided by a commercial electromagnetic solver. The new model showed better efficiency when compared to a similar antenna composed with a metamaterial superstrate.

ID: 413 / PD4: 11

Track 12

Topics: Wave Propagation, Mathematical Modelling and Formulations, Numerical Techniques

Keywords: Computational electromagnetics, Wave propagation, Finite element analysis, Domain decomposition methods, High performance computing

Domain Decomposition Methods for Time-Harmonic Electromagnetic Waves with High Order Whitney Forms

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Classically, domain decomposition methods (DDM) for time-harmonic electromagnetic wave propagation problems make use of the standard, low order, Nédélec basis functions. This paper analyses the convergence rate of DDM when higher order finite elements are used for both volume and interface discretizations, in particular when different orders are used in the volume and on the interfaces.

PD5: Multi-physics and coupled problems 2

Time: Thursday, 02/Jul/2015: 1:45pm - 3:25pm · *Location:* Lounge

Session Chair: Stephane Brisset

Session Chair: Dong-Hun Kim

ID: 27 / PD5: 1

Track 15

Topics: Multi-physics and Coupled Problems

Keywords: Magnets, conducting materials, eddy currents, finite element methods

No-slip motion of a spherical magnet on top of a conductive plate

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The trajectory of a spherical magnet which rolls without slipping on a conductive plate is modelled. A timestepping T-Omega method is used to find the electromagnetic force and torque. The trajectory is computed for different initial conditions and compared to performed experiments.

The contribution has been withdrawn.

Efficiency and optimal control of conductive fluids by MHD actuators

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ID: 150 / PD5: 3

Track 18

Topics: Numerical Techniques, Multi-physics and Coupled Problems

Keywords: Adaptive mesh method, degrees-of-freedom, electric machine, electromagnetic field, finite element method, thermal field

A Single-Mesh Method for Electromagnetic Field and Thermal Field Coupled Finite-Element Analysis

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This paper presents a single-mesh method for electromagnetic field and thermal field coupled finite-element analysis. In the proposed adaptive degrees-of-freedom (DoF) algorithm, only a single mesh is required for both electromagnetic field computation and thermal field computation, while the master-slave technique is adopted to refine or coarsen the distribution of computational DoFs according to the estimated solution errors. This progress can avoid solution interpolation errors due to the changes between the mesh for electromagnetic field computation and the mesh for the thermal field computation. In the meantime, the posteriori error estimator is applied to ensure the accuracies of the solutions. The details of the algorithm are presented and a numerical example using the proposed algorithm is shown to verify its validity and effectiveness in the electromagnetic-thermal co-simulation.

ID: 242 / PD5: 4

Track 18

Topics: Multi-physics and Coupled Problems

Keywords: Electromagnetic fluid, Coupled method, Particle method, FEM, MPS, High-viscosity

Numerical Analysis of High-Viscosity Electromagnetic Fluid Using a Combined Method of Particle Method and FEM

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High-viscosity electromagnetic fluid, which is usually a suspension of extremely fine particles of electric or magnetic characteristics in a carrier fluid, shows unique behaviors such as elongation or sharpening in electromagnetic field. Those behaviors are difficult to calculate with FEM because they include an intensive deformation or a large change of interfacial surface. Therefore we propose an improved combined analysis method of the particle method and FEM to calculate such behaviors of electromagnetic fluid. This research deals with a deformation of electromagnetic fluid which is grown down and sharpened by electric field. Electromagnetic force is calculated with FEM in each step during the deformation and applied to particles of the particle method in the form of external force. Because the fluid have an extremely high-viscosity, an implicit method is used to calculate fluid speed due to viscous term in Navier-Stokes equations. This research also reports a comparison of calculated and measured results.

ID: 410 / PD5: 5

Track 02

Topics: Multi-physics and Coupled Problems

Keywords: coupled simulation, electromagnetic-thermal-deformation-fluid, levitation melting, Titanium

Electromagnetic-thermal-deformed-fluid Coupled Simulation for Levitation Melting of Titanium

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A numerical simulation considering electromagnetic-thermal-deformation-fluid of levitation melting is performed by using the finite element method (FEM). The simulation is conducted by considering the two-way interactions of multiphysics field. Material properties in melting area is nonlinear. Surface-to-surface radiation, phase change, deformation in the melting process and fluid flow are also considered. Dependence of excitation power parameters of coils and melting metal's temperature, lifting force exerted on sample, deformation and velocity magnitude are assessed. Through this simulation, the relationships between different physics fields are obtained so that it is helpful for smelting high pure metals.

ID: 471 / PD5: 6**Track 15***Topics:* Multi-physics and Coupled Problems*Keywords:* Mechanical watch, resonance frequency, coupled magneto-mechanic problem**Modeling of magnetic field perturbations on the balance-spring of a mechanical watch****Refzul Khairi, Xavier Mininger, Romain Corcolle, Lionel Pichon, Laurent Bernard**GeePs, CNRS UMR 8507, SUPELEC, UPMC, Univ Paris Sud, Univ. Paris-Saclay; xavier.mininger@lgep.supelec.fr

A magnetic field is a major enemy of a mechanical watch. This field may modify the structure of the balance-spring and change its resonance frequency. As a consequence, the watch loses its accuracy. The aim of this work is to quantify the impact of the magnetic field to the balance-spring resonance using a finite element approach. This coupled magneto-mechanical problem implies magnetic forces computation while accounting for a large rotation of the spring. An original algorithm including a dynamic mechanical time-stepping scheme is proposed to quantify the change of the resonance frequency.

ID: 488 / PD5: 7**Track 18***Topics:* Numerical Techniques, Multi-physics and Coupled Problems*Keywords:* Finite element analysis, Convergence of numerical methods, Nonlinear systems, Microactuators**Comparison of Nonlinear Domain Decomposition Schemes for Coupled Electromechanical Problems****Alexandre Halbach, Patrick Dular, Christophe Geuzaine**University of Liège, Belgium; alexandre.halbach@ulg.ac.be

The aim of this paper is to compare several domain decomposition schemes for nonlinear, coupled electromechanical problems. Both staggered and monolithic electrostatic/elastic formulations are combined with an overlapping domain decomposition method applied either to the uncoupled, linear staggered resolutions or to the monolithic nonlinear system. The influence of the elastic waves frequency, of the electrostatic potential and of the mesh on the convergence rate is investigated on a simple 2D model of a vibrating micromembrane array

ID: 559 / PD5: 8**Track 18***Topics:* Multi-physics and Coupled Problems*Keywords:* Finite element method, eddy current, thermal analysis, temperature dependence, gas-insulated bus bar**Magnetic Eddy-Current, Fluid and Thermal Coupled Models for the Finite Element Behavior Analysis of Gas-Insulated Bus Bars****Xiaowen Wu¹, Nianguang Zhou¹, Chunming Pei², Ling Li³, Bing Kang³, Xiangyu Guan³**¹State Grid Hunan Electric Power Corporation Research Institute, China, People's Republic of; ²China Electric Power Research Institute; ³School of Electrical Engineering, Wuhan University; whuwxw@outlook.com

Knowledge of the thermal behavior of gas-insulated bus bars plays an important role in the design process in order to keep the operation temperature at safe level. In this paper, the coupled magnetic eddy-current, fluid and thermal problem in a three-phase gas-insulated bus bar (GIB) is solved by the finite-element method (FEM). The magnetic eddy-current field is indirectly coupled into the fluid and thermal fields by considering the temperature dependent electric and thermal properties of the materials in the GIB. Multiple species transport technique is employed in the thermal model, eliminating the need of convective heat transfer boundary conditions. The proposed methodology is validated with the experimental temperature rise results. With the proposed model, the steady- and transient-state thermal behaviors of the GIB in various operation conditions are analyzed.

ID: 585 / PD5: 9**Track 08***Topics:* Multi-physics and Coupled Problems*Keywords:* core loss, magnetostriction, shrink-fitting, stress, vibration**Effect of Shrink-Fitting and Magnetostriction on Core Loss and Vibration of Permanent Magnet Motor****Hassan Ebrahimi, Yanhui Gao, Hiroshi Dozono, Kazuhiro Muramatsu**Saga University, Japan; hx_ex@yahoo.com

A method of three-dimensional finite element magneto-mechanical analysis is developed to investigate the effect of magnetostriction and stress, including shrink-fit stress and stress due to electromagnetism and magnetostriction, on the core loss and the vibration of motors. Shrink-fit stress calculation is carried out using static structural analysis and equivalent thermal nodal force calculated by a novel method using the thermal stress tensor. Three-dimensional structural dynamic analysis is carried out with time step-size small enough to capture the vibration characteristics of electrical machines due to the inverter switching frequency. The method is applied to the core loss and vibration analysis of a permanent magnet motor. Numerical results show that the core loss of stator nearly doubles due to the shrink-fit stress. The stress, however, has a negligible effect on the motor vibration.

ID: 637 / PD5: 10**Track 15***Topics:* Static and Quasi-Static Fields, Multi-physics and Coupled Problems, Novel Computational Methods for Machines and Devices

Keywords: Generator circuit-breakers, isolated phase busducts, short circuit currents, electromagnetic modelling, numerical simulation, and magnetomechanical effects.

Modelling and Simulation Aspects of Transient Electromagnetic-Mechanical Analysis for Industrial Applications

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For the development and optimization of those power system components that are subjected to high short circuit currents, such as for example Generator Circuit Breakers (GCB) and Insulated Phase Busducts (IPB), an accurate, robust and efficient methodology for performing a transient electromagnetic-mechanical analysis is of paramount importance. The purpose of this paper is to present numerical and modelling aspects of the analysis that are decisive for the accuracy and reliability of the results. The efficient and robust 3-D approach based on Biot-Savart integration for evaluating the electromagnetic force density over electrically conductive domains, the 3-D magnetostatic approach based on the A-field formulation including an air box, and the 3-D eddy-currents approach based on the A- ϕ -field formulation are compared in order to evaluate the importance and relevance of magnetic bodies consideration (structural steel components) in terms of electromagnetic force and induced eddy-currents for daily design of GCBs.

ID: 640 / PD5: 11

Track 16

Topics: Mathematical Modelling and Formulations, Numerical Techniques, Multi-physics and Coupled Problems

Keywords: Differential algebraic equations, Electro-thermal coupling, Error correction, Fractional time step.

A Multilevel Error-Correction Scheme for the Electro-Thermal Modelling of Device Structures

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Design of devices in nano-electronics generally yields strongly coupled problems in time-domain. The solution of such problems formally entails a monolithic approach that is certainly characterised by a large system matrix. In this paper, a multilevel error correction scheme is proposed within the context of electro-thermal coupling in device structures. The scheme avoids the computational burden of a monolithic implementation and retains the convergence order in time by conveniently solving an error equation in a recursive fashion. The method can also be integrated with any order reduction technique.

ID: 662 / PD5: 12

Track 18

Topics: Multi-physics and Coupled Problems

Keywords: Vegetable Oil, Magnetic Nanoparticle, Magnetoconvection, Cooling, Magnetic-Thermal-Fluidic Analysis, Multiphysics

Cooling Performance of Vegetable Oil-Based Magnetic Nanofluid Due to Magnetoconvection Effects

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This paper presents the cooling performance of vegetable oil-based magnetic nanofluids with the different volume fractions of magnetic nanoparticles due to magnetoconvection effects along with the externally applied magnetic field. The mineral-based oil has been usually used in power transformer because it has high dielectric strength and good cooling performance under operating condition. Due to the environmental impact, the eco-friendly vegetable transformer oils have been substituted for mineral-based insulating oils. Until now, several studies reported only the characteristics of dielectric breakdown with vegetable oil-based magnetic nanofluids without any real electromagnetic systems. The thermal characteristics of vegetable oil-based magnetic nanofluid, however, have not been fully discussed yet. The aim of our study, therefore, was to examine the cooling performance by adding the magnetic nanoparticles into the vegetable transformer oil. To analyze this effect quantitatively, a multiphysics technic coupled with magnetic-thermal-fluidic fields was developed by use of the quasi-static magnetic field approximation and conjugate heat transfer. To validate our numerical setup, some experiments were successfully carried out in a simple electromagnetic system with different insulating liquids.

ID: 5 / PD5: 13

Track 12

Topics: Static and Quasi-Static Fields, Multi-physics and Coupled Problems

Keywords: Power system protection, arresters, thermal stability, nonlinear dynamical systems.

EQST Modeling and Simulation of Surge Arresters

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A coupled electro-quasistatic-thermal (EQST) method for the simulation of surge arresters is developed. In order to cope with the extremely short time scales associated with the strongly nonlinear electrical characteristic of the metal-oxide (MO) varistor material, a multi-rate time integration technique is adopted. Besides, a model for the heat transfer in the arrester air gap is developed which takes into account radiation and natural convection by means of a nonlinear equivalent material. 2-Dimensional-Finite-Element-Method (2D-FEM) simulations for a large 550-kV-system station class arrester in continuous operation are carried out and validated against measurements. Furthermore, the method is used for the investigation of thermal stability under pulsed overvoltages as specified by the IEC operating duty test.

ID: 363 / PD5: 14

Track 09

Topics: Numerical Techniques, Multi-physics and Coupled Problems

Keywords: Coupled problems, Induction Heating, Laser Beam Welding, Cell Method.

Numerical Simulation of Induction Assisted Laser Beam Welding

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The laser beam welding is an efficient industrial process used to join metallic pieces and it is commonly used in many applications. Unfortunately, due to the high values of space and time thermal gradients created by the beam, problems can occur in the metallurgy of the seam that usually affect the joint mechanical properties. One proposed solution is the use of induction heating, placed close to the laser beam, that can smooth out the thermal gradients controlling the metallurgical structure of the welded material. The simulation of this industrial process requires the analysis of both heating sources (laser beam and induction heating) coupling together the electromagnetic and the thermal phenomena. To this aim, a specific analysis tool has been developed that can take into account all the peculiarities of the phenomena. The procedure is based on the Cell Method and its novelty lies in the use of a coupled electromagnetic-thermal procedure taking into account the laser modelling. The description of the procedure together with some obtained results are presented.

PD6: Novel computational methods for machines and devices 4

Time: Thursday, 02/Jul/2015: 1:45pm - 3:25pm · Location: Lounge

Session Chair: Behzad Forghani

Session Chair: Milica Popovich

ID: 131 / PD6: 1

Track 08

Topics: Optimization and Design, Novel Computational Methods for Machines and Devices

Keywords: Electrical machine, data assimilation, measurement probes, numerical simulation

Estimation of FEM model parameters using data assimilation - Application to an electrical machine

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The goal of this paper is to identify the real parameter set of a given machine. The identification method is based on data assimilation coupled with a FEM model. Data assimilation method is an optimization approach that limit the space of candidate parameter sets by centering it to the ideal machine. An application to an electrical machine is presented based on the analysis of flux probe signals.

ID: 159 / PD6: 2

Track 06

Topics: Novel Computational Methods for Machines and Devices

Keywords: Circuit equations, Finite element analysis, Fourier series, Induction machine, Wound rotor

A Fast Computation of Wound Rotor Induction Machines Based on Coupled Finite Elements and Circuit Equations under a First Space Harmonic Approximation

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The paper presents a fast method to compute wound rotor induction machines in steady state. Coupled time-harmonic FE-circuit equations are used under a first space harmonic approximation for the air-gap magnetic field. It is shown that only 4 magnetostatic FE computations are necessary to compute the machine performances for a wide range of operating speeds. The performances comparison to a conventional complex magnetodynamic FE analysis shows the effectiveness of the proposed approach.

ID: 239 / PD6: 3

Track 16

Topics: Static and Quasi-Static Fields, Mathematical Modelling and Formulations, Novel Computational Methods for Machines and Devices

Keywords: transformer cores, magnetic flux leakage, equivalent circuits, finite element analysis

Fast Calculation of the Core Flux for a Transformer with Increased Leakage Inductance

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The particular class of two-winding transformers is considered, for which the knowledge of the core flux density under load condition plays the key role. The standard field-circuit model of a transformer does not give reliable answer due to computational difficulties and physical uncertainty of leakage inductance of two coils having a strong magnetic coupling.

The reformulation of well-known equivalent circuit is proposed, in such a way that all the inductances in it have the clear physical sense in order to be directly measured or modelled by FEA. The results of 2D and 3D FEA simulation compared to each other and with the measured data. It is shown that for transformer design purpose the 2D simulation gives sufficient accuracy. The proposed model is also applicable for a multi-winding transformer used for energy efficient arc welding invertors.

ID: 276 / PD6: 4

Track 05

Topics: Novel Computational Methods for Machines and Devices

Keywords: eddy currents, induction heating device, method of images, linear motion

Eddy currents computation in translational motion conductive plate of an induction heater with consideration of finite length extremity effects

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An electromagnetic model is proposed to compute translational motion eddy current in a conductive plate. The eddy currents are due to the movement of the plate in a dc magnetic field created by a PM inductor. Firstly, the magnetic field due to the PMs is computed in 3D where the iron yokes influence is considered thanks to the method of images. Then, the motional eddy currents are computed such that the edge effects are correctly taken into account through an iterative procedure which uses magnetic images. The computations are very fast and the obtained results are close to those issued from 3D FE method and from experiments

ID: 294 / PD6: 5

Track 08

Topics: Novel Computational Methods for Machines and Devices

Keywords: Aerospace industry, finite element methods, induction motors, permanent magnet motors

Analysis of Induction and Permanent Magnet Motors for Aerospace Applications Using Multiple Slices FE Technique and Pseudo-cooling Thermal Boundary Conditions

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Two original numerical techniques are developed for the finite element (FE) transient analysis of induction and permanent magnet motors operating in demanding aerospace applications. The first technique is the electromagnetic and thermal analysis weak coupling using a multiple slices 2D FE model. The advantage of the specific technique is the representation of complex actuator geometries including skewed magnets and winding ends, by using a low computational cost 2D model while taking into consideration temperature dependent material attributes. The second technique consists in the development of properly defined boundary conditions for the emulation of the cooling housing of actuators. Those boundary conditions are applied at the outer surface of the actuators in contact with the housing and eliminate the need of modeling complex 3D geometries of highly integrated actuator housings.

ID: 326 / PD6: 6

Track 02

Topics: Novel Computational Methods for Machines and Devices

Keywords: Brushless doubly fed induction generator, parameters calculation, Finite element method (FEM).

Calculation of Equivalent Circuit Parameters of Brushless Doubly Fed Induction Generator Using Finite Elements

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A new method based on two-dimensional finite element analysis is proposed to improve the equivalent circuit calculation of brushless doubly fed induction generator (BDFIG). The calculation is divided into four parts: firstly, the modelling for per-phase equivalent circuit is proposed; secondly, calculation of the basic parameters is given; thirdly, due to the complex distribution and saturation effect of the magnetic fields in the machine, interaction between the two magnetic fields in the calculation of magnetizing reactance is directly considered; finally, the slot leakage reactance and the harmonic reactance are separated. An experimental test is carried out on a 30kW prototype BDFIG to confirm the accuracy of the proposed method.

ID: 385 / PD6: 7

Track 18

Topics: Novel Computational Methods for Machines and Devices

Keywords: Electromagnetic field simulation, Josephson Effect, Josephson junction, quantum magnetic simulation, SQUID

Numerical simulation of HTS dc-SQUID by FEM coupling with circuit equation taking into account phase difference of Josephson junction

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An HTS SQUID is a high sensitive magnetic sensor. The SQUID has been widely studied for various applications. In those applications, the magnetic shielding environment is required for stable operation of the SQUID. The reason why the magnetic shielding is employed is that the SQUID is adversely affected by the magnetic noise. Because of the background, the high robustness with respect to the magnetic noise is needed for the SQUID. To attain the SQUID operation without magnetic shielding environment, it is necessary to clarify the phenomenon inside of the SQUID and improve the performance. However, the phenomenon such as quantum and electromagnetic behaviors has not been comprehended yet. In our study, the FEM is employed to simulate the electromagnetic behavior of the SQUID and coupled with the equivalent circuit of the Josephson junction to consider the quantum behavior. By using the proposed simulation method, the numerical simulation of SQUID is performed taking into account both of the electromagnetic and quantum behavior. In the paper, the characteristics of SQUID that is affected by the amount of the external magnetic flux are shown.

ID: 430 / PD6: 8

Track 06

Topics: Novel Computational Methods for Machines and Devices

Keywords: Brushless motors, AC motors, Commutation, Coupled mode analysis, Finite element method

Proposed Commutation Method for Performance Improvement of Brushless DC Motor

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This study focused on efficiency improvement of BLDC motors via reduction of torque ripple, core loss, and permanent magnet loss. To achieve this objective, we proposed an improved 150° commutation method for three-phase permanent magnet brushless DC (BLDC) motors to improve the current waveform. Although the 120° commutation method is generally employed for a BLDC motor, the 150° commutation method is introduced in order to operate the BLDC with the same efficiency as a brushless AC (BLAC) motor. Moreover, an improved 150° commutation is proposed to reduce the phase current harmonics. The study investigates the attributes of different commutation methods analytically and experimentally in order to determine the optimal commutation method. The result of this study indicates that the improved 150° commutation method is optimum in terms of harmonic attributes, and reduced torque ripple, thereby improving the motor's efficiency.

ID: 498 / PD6: 9

Track 02

Topics: Static and Quasi-Static Fields, Novel Computational Methods for Machines and Devices

Keywords: Computational electromagnetics, finite element analysis, inductance, magnetic hysteresis

Magnetic Field Analysis of Reactors for Power Conditioner System Taking Account of Hysteretic Property

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Generally, a reactor in a power conditioner is used under DC or AC excitation with high-frequency current ripples. Under DC-biased situation, the magnetic field analysis of the reactor based on a magnetization curve is not sufficiently accurate because the operating point of the reactor is on minor loops. Additionally, it requires a lot of time steps to analyze the reactor excited by commercial-frequency AC with high-frequency ripple in order to consider harmonic components accurately, which results in large computational cost. In this paper, we investigate two inductance calculation methods: one is based on a magnetization curve, and the other is based on the play model in order to take account of hysteretic property. Furthermore, we propose a practical method for calculating iron loss under AC excitation with high-frequency ripple. In this proposed method, the fundamental and harmonic iron losses are calculated separately. In order to verify the validity of the proposed method, the iron loss analysis of an AC reactor is performed.

ID: 563 / PD6: 10

Track 07

Topics: Optimization and Design, Novel Computational Methods for Machines and Devices

Keywords: demagnetization, finite element analysis, nonlinear magnetics, operating point, permanent magnet motors

Characteristics of IPMSM According to Rotor Design Considering Nonlinearity of Permanent Magnet

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Permanent Magnet (PM) motors have been widely used and studied for a long time to acquire high efficiency, high power, and minimization of volume since their output power per unit volume and power factors are high. As a result, there has been extensive research on improving performance of PM. For example, a Dy free anisotropic bonded NdFeB PM named 'MAGFINE' using dynamic Hydrogenation Decomposition Desorption Recombination (d-HDDR) treatment from Aichi Steel Corporation has been developed. The Dy free anisotropic bonded NdFeB PM exhibits a high magnetic energy product compared to ferrite PM, and is cheaper compared to sintered NdFeB PM. However, the NdFeB PM shows nonlinear demagnetization curve.

In this paper, considering the nonlinearity of PM, the operating point calculation process was proposed, and the process was applied to 2D magneto static field Finite Element Analysis (FEA) to study the properties of Interior Permanent Magnet Synchronous Motor (IPMSM) for different rotor designs.

ID: 577 / PD6: 11

Track 05

Topics: Novel Computational Methods for Machines and Devices

Keywords: aligning magnetic field, manufacturing processes, permanent magnet, residual magnetic flux density

Calculation of Residual Magnetic Flux Density Distribution with Consideration of Aligning Field for Anisotropic Bonded NdFeB Magnets

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This paper presents a residual magnetic flux density (Br) distribution analysis method for an anisotropic bonded NdFeB permanent magnet taking into account aligning field during the forming process. To manufacture the anisotropic bonded NdFeB magnet, the magnet powders need to be aligned with proper aligning field before magnetizing. Therefore, it is necessary to analyze Br distribution with the results of aligning field analysis. In order to estimate the Br distribution, an analysis method by combining the electric circuit equation coupled with the transient finite element method (FEM) and the scalar Jiles-Atherton hysteresis model is proposed.

ID: 593 / PD6: 12

Track 15

Topics: Optimization and Design

Keywords: magnetization, design, permanent magnet magnetization

A Study on Design of Magnetization Yoke of Ferrite Spoke-Type Permanent Magnet Synchronous Motor considering Demagnetization

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The study propose a design of magnetization yoke of ferrite spoke-type permanent magnet synchronous motor. A high magnetic field intensity(H) is required for the magnetization of permanent magnet, meaning that the analysis of nonlinear finite elements methods is needed considering saturation of core. The permanent magnet is placed deeply to the shaft especially in spoke-type motor. The high H, however, may cause demagnetization of surrounding permanent magnets, making the design of spoke-type magnetization yoke to be difficult. This study proposes the interpole winding to reduce the demagnetization of surrounding permanent magnets and analysis of power supply source considering magnetizer, derives the structure of optimized magnetization yoke to meeting the criteria of magnetization and demagnetization by analyzing field, and finally verifies the results of this study by manufacturing and testing.

ID: 606 / PD6: 13

Track 07

Topics: Optimization and Design

Keywords: Spoke type Motor, Magnetizer, Cogging torque and torque ripple

Optimum Shape Design of Spoke Type Motor and Magnetizer using Finite Element Method and Response Surface Method

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This paper proposes criteria for an optimal shape design and a magnetizer system design to be used for a high-output spoke type motor. The paper also discusses methods of reducing high cogging torque and torque ripple, in order to prevent noise and vibration. The optimal design of the stator and rotor can be enhanced using Response Surface Method (RSM) and Finite Element Method (FEM).

In addition, a magnetizer system has been optimally designed for the magnetization of permanent magnets to be used in the motor. Finally, this paper verifies that the proposed motor can efficiently replace interior permanent magnet synchronous motor (IPMSM) in many industries.

ID: 658 / PD6: 14

Track 04

Topics: Novel Computational Methods for Machines and Devices

Keywords: PWM current, current harmonic, finite element analysis, PWM losses, core-losses

PWM Core-loss Analysis of Permanent Magnet Motor using Current Harmonic Component

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In this paper, we propose the use of the fast finite element method (FEM) for the nonlinear analysis of a pulse-width modulation (PWM) current source. Using FEM analysis, PWM current analysis is time consuming because it has many steps, unlike the case with a sinusoidal current. In this paper, we perform the FEM analysis in two steps. First, the sinusoidal current is applied to the nonlinear analysis and each permeability value is saved in memory. Second, we perform the linear analysis using the saved permeability value. To verify the effectiveness of this approach, the core loss of the proposed method is compared with that of the full-FEM result.

ID: 666 / PD6: 15

Track 12

Topics: Electromagnetic Compatibility, Optimization and Design, Novel Computational Methods for Machines and Devices

Keywords: Bearing currents, electromagnetic shield, copper wedge, PWM inverter

Suppression for Discharge Bearing Currents in Variable-Frequency Motors Based on Electromagnetic Shield

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High frequency current in the bearings of variable-frequency motors coupled with their shafts is a common issue that will shorten the bearings lifetime ultimately. A new method could be used to suppress high frequency discharge bearing currents (HFDBC) was proposed in this paper. In this method, an electromagnetic shielding slot wedge (ESLW) was used to reduce the capacitive coupling between the stator windings and the rotor. From the perspective of electromagnetic field, electromagnetic coupling caused by the common mode voltage could be blocked by this electromagnetic shield layer. Additionally, the mathematic model of suppression method was given and the starting performance of the motor was analyzed. Finally, an experimental platform was set up and a motor was modified to evaluate the suppressing effectiveness. The shaft voltage and bearing currents of the modified motor, under ESLW layer presented and absent, were measured and compared, and the effects of the shielding slot wedge were evaluated respectively when the motor operated at load and no-load.

ID: 692 / PD6: 16

Two Pages Short Version

Topics: Novel Computational Methods for Machines and Devices

Keywords: Magnetic fields, finite element analysis, axial flux permanent magnet motor.

Applying superposition of 2D results to model 3D field distributions in magnetically linear devices using an example of an axial flux permanent magnet coreless motor

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The paper focuses on methodologies for field simulation in magnetically linear devices using an example of an axial flux permanent magnet coreless motor. Two approaches are investigated, both relying on representing the true 3D field patterns by superimposing axisymmetric 2D solutions, one harnessing the finite element modelling and another based directly on the Biot-Savart law. The results have been compared with full 3D solution using commercial software and verified experimentally.

ID: 543 / PD6: 17

Track 08

Topics: Novel Computational Methods for Machines and Devices

Keywords: Permanent magnet motors, stress, losses, finite element methods.

3-D Electromagnetic Field Analysis Combined with Mechanical Stress Analysis for Interior Permanent Magnet Synchronous Motors

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The method of 3-D electromagnetic field analysis combined with mechanical stress analysis has been developed for loss calculation of interior permanent magnet motors. Both the stator compressive stress caused by shrink fitting and the rotor tensile stress caused by centrifugal force are considered in the stress analysis. The 3-D flux density vector is calculated by the electromagnetic field analysis including the core end regions. The variation in the stress effect with the angle between stress and flux vectors is taken into account by using equivalent stress. The calculated loss is compared with the experimental loss in order to confirm the validity of the analysis. It is clarified that not only the compressive stress caused by the stator shrink fitting but also the tensile stress caused by the rotor centrifugal force affect the electromagnetic field in the interior permanent magnet motors.

ID: 338 / PD6: 18

Track 05

Topics: Optimization and Design

Keywords: Spherical Actuator, outer rotor, 3-DOF, control method, 3-D FEM

Analysis of 3-DOF Outer Rotor Spherical Actuator Employing 3-D FEM

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We have been developing various kinds of 3-DOF electromagnetic spherical actuators. Some problems such as low torque, large size and narrow rotation angle remain to apply these actuators to robot joints. In this paper, we present a new 3-DOF spherical actuator whose rotor is on the outside to solve these problems. The basic structure and operating principle of this actuator are described. The static and dynamic performances are analyzed using 3D-FEM, in which two types of control methods are taken into account.

ID: 406 / PD6: 19

Track 14

Topics: Optimization and Design, Novel Computational Methods for Machines and Devices

Keywords: Analytic method, conformal mapping, interior permanent magnet synchronous motor, magnetic equivalent circuit.

Cogging Torque Minimization Design in Interior Permanent Magnet Motor by Using an Analytical Method

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This paper presents a new magnetic equivalent circuit (MEC) model for calculating the cogging torque in an interior permanent magnet synchronous motors (IPMSMs). Since the proposed method can take into account the slotting effect and magnet end effect, the analysis and design of IPMSMs can be conducted correctly and rapidly despite no use of a finite element method (FEM). Its validity was confirmed by comparing the results of the proposed method with those of FEM. Furthermore, the optimal design result considering various objectives is elicited by using the proposed method.

ID: 393 / PD6: 20

Track 09

Topics: Novel Computational Methods for Machines and Devices

Keywords: Permanent magnet machines, finite element analysis, magnetic circuit, magnetic flux density

Computational Method of Remanence Flux Density to Consider Overhang Effect in 2-D Analysis by Using Magnetic Energy

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According to conventional study, it is possible to conduct two-dimensional (2-D) finite element analysis (FEA) that takes overhang effect into account through adjusted remanence flux density by applying overhang parameter. The latest study has found that overhang parameter can be obtained through variation of operating point of permanent magnet. In this study, we propose computational method to calculate remanence flux density accurately that considers overhang effect in 2-D FEA by using magnetic energy of permanent magnet. Proposed method is verified by comparison with results of three-dimensional FEA.

ID: 130 / PD6: 21

Track 06

Topics: Novel Computational Methods for Machines and Devices

Keywords: Claw Pole Machine, Finite Element Method, Eccentricity, Stator Deformation, Uncertainty Quantification

Study of the influence of the fabrication process imperfections on the performances of a claw pole synchronous machine using a stochastic approach

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In mass production, fabrication processes of electrical machines are not perfectly repeatable with time leading to dispersion on the dimensions which are not equal to their nominal values. The issue is then to evaluate the influence of these dispersions on the performances of the electrical machines. In this communication, a stochastic approach coupled with a 3D Finite Element model is used to study the influence of the fabrication process imperfections like the rotor eccentricity and the stator deformation. The novelty of this paper relies on the machine type studied but also on the fact that the stochastic approach has been fully applied that is to say input random variables representing the imperfections have been characterized from a measurement campaign.

ID: 571 / PD6: 22

Track 05

Topics: Material Modelling, Novel Computational Methods for Machines and Devices

Keywords: Ferrite magnet, magnetization level, magnetization processes, magnetizing fixture, post assembly magnetization

Estimation of Rotor Type Using Ferrite Magnet Considering the Magnetization Process

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This paper deals with the post assembly magnetization process of motors using ferrite permanent magnets. In order to meet the needs of mass production, most motors are magnetized post assembly. However, increasingly complex shapes are required to maximize the flux of permanent magnets. As a result, certain locations in the magnet are not fully magnetized by the magnetizing fixture due to insufficient magnetomotive force. Therefore, an analysis concerning the post assembly magnetization is needed. In this paper, the concentrated flux spoke type synchronous motor is analyzed to magnetization process, and then the magnetization level is compared by linkage flux value between post assembly and fully magnetization. Finally, back electromotive force is estimated by post assembly magnetization method the according to the magnet shape.

ID: 469 / PD6: 23

Track 10

Topics: Numerical Techniques, Novel Computational Methods for Machines and Devices

Keywords: Eddy currents, Finite element analysis, Adaptive mesh refinement, Induction motors

A Magnetodynamic Error Criterion and an Adaptive Meshing Strategy for Eddy Current Evaluation

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In order to address their considerable impacts on both the energy efficiency and performance requirements, eddy current modeling and its accuracy are discussed from a thermodynamic approach. Coupled with an adaptative meshing strategy, some numerical results are given on an induction machine.

OA8: Multi-physics and coupled problems

Time: Thursday, 02/Jul/2015: 3:50pm - 5:30pm · Location: Room #0100

Session Chair: Stephane Clenet

Session Chair: Patrick Dular

ID: 280 / OA8: 1

Track 02

Topics: Numerical Techniques, Multi-physics and Coupled Problems

Keywords: Finite element methods, Galerkin method, Modeling, Field projection.

Space-Time Galerkin Projection of Electro-Magnetic Fields

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Spatial Galerkin projection transfers fields between different meshes. In the area of finite element analysis of electromagnetic fields, it provides great convenience for remeshing, multi-physics, domain decomposition methods, etc. In this paper, a space-time Galerkin projection is developed in order to transfer fields between different spatial and temporal discretization bases.

ID: 422 / OA8: 2

Track 15

Topics: Multi-physics and Coupled Problems

Keywords: Electromagneto-mechanical coupling, Eddy currents, Magnetic Damping, Integral formulation, Edge elements.

Numerical Model of the Dynamic Response of 3D Conducting Structures with Magnetic Damping

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In this paper, we present a numerical model for the solution of the classic electromagneto-mechanical coupled problem. The dynamical behavior of conducting structures in the presence of a strong magnetic damping was the subject of a high scientific interest in the past, leading to several computational models with experimental validation, mainly related to thin shell structures. We extend this approach to the treatment of three-dimensional conducting structures. To this purpose, we couple a very effective 3D integral formulation in terms of the current density to the 3D dynamical model of the conducting structures. The formulation is validated against the experimental results of the TEAM-16 benchmark problem. In the full paper, the importance of the magnetic damping will be assessed with reference to the analysis of dynamic response of the vacuum vessel of a fusion device under the strong Lorentz forces due to the plasma current disruption. The complex geometry of the vacuum vessel represents a real challenging problem in this frame.

ID: 109 / OA8: 3

Track 16

Topics: Multi-physics and Coupled Problems, Multi-scale modelling and homogenization

Keywords: Coupled problems, Eddy currents, Magnetic resonance imaging, Thermal analysis

Coupled magneto-thermal analysis of split gradient coils in MRI scanners

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This paper describes the coupled electromagnetic-thermal analysis of gradient coils in magnetic resonance imaging. This application deserves special attention because the eddy-current analysis of gradient coils is usually performed using filamentary and shell elements, while thermal analysis requires volume elements. The paper aims to present a seamless method to couple the mixed-element discretizations (1d, 2d and 3d) and to project the outputs of eddy currents simulation into the corresponding thermal sources. Special attention is devoted to managing of non-simply connected domains within the integral shell elements formulation.

ID: 512 / OA8: 4

Track 08

Topics: Multi-physics and Coupled Problems

Keywords: Magnetoelectric effect, interdigitated electrodes, finite element formulation, magnetostriction, piezoelectricity

Finite Element Modeling of Magnetoelectric Composites with Interdigitated Electrodes

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Magnetoelectric effect in composite materials results from the combination of piezoelectric and magnetostrictive effects via elastic interaction. This work focuses on the modeling of magnetoelectric multilayer structures with interdigitated electrodes. A finite element formulation for such coupled problems, taking into account the nonlinearity of magnetostrictive material, and an application to a magnetic sensor are presented.

ID: 521 / OA8: 5

Track 06

Topics: Numerical Techniques, Multi-physics and Coupled Problems

Keywords: Circuit simulation, Coupling circuits, Circuit subsystems, Electromagnetic devices, Stability criteria, Convergence

Coupling Interfaces and their Impact in Field/Circuit Co-Simulation

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Co-simulation is an important approach for coupled systems in time domain analysis. Dealing with coupled systems, convergence depends on the computational order in which the parts are solved and on certain contraction properties. This paper takes a closer look at the coupling structure of field/circuit coupled problems and introduce a new approach, where we can derive information about stability and contraction directly from the network structure, without informations regarding the embedded EM device or the circuit part.

When co-simulation is applied to embedded EM-devices, the standard approach is to distinguish clearly between the field and circuit part. However, we show that this does not always work best and demonstrate that using a specific interface for coupling, co-simulation reached better properties, e.g. concerning the computational effort.