FINITE ELEMENT MODELLING OF MAGNETIC FIELDS AND CALCULATION OF STATIC CHARACTERISTICS OF LINEAR STEP MOTORS FOR CONTROL ROD DRIVES OF NUCLEAR REACTORS

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ABSTRACT

This paper describes an accurate method for the calculation of static characteristics of linear step motors (LSM) used as actuators in control rod drives (CRD) of nuclear reactors. By static characteristic of the LSM is meant the electromagnetic force developed by the motor versus armature displacement curve that determines motor performance in its standing and dynamic modes of operation. The method is based on the modelling and computation of nonlinear axisymmetric magnetic fields in LSM using the finite element (FE) technique. Some of the simulation results are compared with available experimental data which validates the developed method.

INTRODUCTION

In recent years variable reluctance linear step motors have opened up a new horizon in the design of safe and reliable linear discrete electromagnetic actuating mechanisms for CRD of nuclear reactors [1-3]. These CRD, the heart of which is formed by LSM ensure controllability of energy output both locally and globally over the entire volume of the reactor core. This is important for the safe, reliable and economic exploitation of large nuclear reactors. Figure 1 shows the kinematic and structural diagrams of a linear electromagnetic actuating mechanism with LSM. LSM (1, 2) in this case combines the functions of the motor (M), holding mechanism (HM), reduction gear (RG), and end and continuous position feedback detectors (EPD, CPD). In addition to these, LSM can act as a braking mechanism (BM) and the gravitational force on control rods (CR)[2] - as an independent energy source (IES) which can be used to release the armature (2) into the reactor core (5) in case of an emergency. This simplicity in kinematics makes the CRD with LSM safe and highly reliable. Besides, these motors deliver fast response, high positional accuracy and wide range speed control.

The static characteristic is one of the most important performance characteristics of above linear step motors. Since they typically operate in the standstill mode and the switching frequency of phase windings is low (except for emergencies) this characteristic virtually determines the feasibility of a given motor design. It is subject to variations by nonlinearities due to complex saturation conditions which depend not only on the winding currents but also on the mutual
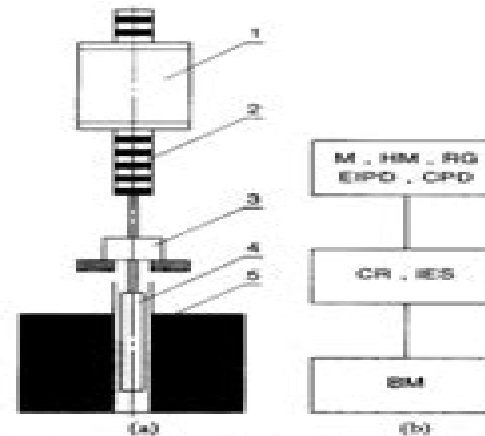

Figure 1. Kinematic (a) and structural (b) block diagrams of actuating mechanism with LSM

alignments of stator and the moving armature. These factors have to be taken into account for the accurate calculation of static characteristics of LSM which forms the essential part of their CAD, optimisation, performance evaluation and prediction. Unlike rotating step motors, various aspects of the theory and design of which are well studied [4, 5] at present there are not many published papers which concern linear step motors [6-9]. Considering this, two methods have been developed for calculating the static characteristics and performance analysis of above LSM [10]. The first method based on performance analysis approach [8, 11] is an approximate one and gives satisfactory results for small stator currents and weak iron saturation [12]. It proved to be useful for the fast evaluation of motor characteristics at the initial stages of their design process. Furthermore, it quantitatively justifies the need for an accurate field modelling approach [13] on which the second method, described in this paper is based. This accurate method was used to calculate and analyse the static

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<u>Finite Element Modelling of Static and Stationary Electric and Magnetic Fields</u> Ioan Ernest Lager,1996-11 **The Finite Element Modeling of Static and Stationary Electric and Magnetic Fields** Ioan E. Lager,Gerrit Mur,1994

The Least-Squares Finite Element Method Bo-nan Jiang,2013-03-14 Here is a comprehensive introduction to the least squares finite element method LSFEM for numerical solution of PDEs It covers the theory for first order systems particularly the div curl and the div curl grad system Then LSFEM is applied systematically to permissible boundary conditions for the incompressible Navier Stokes equations to show that the divergence equations in the Maxwell equations are not redundant and to derive equivalent second order versions of the Navier Stokes equations and the Maxwell equations LSFEM is simple efficient and robust and can solve a wide range of problems in fluid dynamics and electromagnetics including incompressible viscous flows rotational inviscid flows low Mach number compressible flows two fluid and convective flows scattering waves etc *Scientific Computing in Electrical Engineering SCEE 2008* Luis R.J. Costa,Janne Roos,2010-06-14 This book is a collection of 65 selected papers presented at the 7th International Conference on Scientific Computing in Electrical Engineering SCEE held in Espoo Finland in 2008 The aim of the SCEE 2008 conference was to bring together scientists from academia and industry e g mathematicians electrical engineers computer scientists and physicists with the goal of intensive discussions on industrially relevant mathematical problems with an emphasis on modeling and numerical simulation of electronic circuits and devices electromagnetic fields and coupled problems This extensive reference work is divided into five parts 1 Computational electromagnetics 2 Circuit simulation 3 Coupled problems 4 Mathematical and computational methods and 5 Model order reduction Each part starts with an general introduction followed by the actual papers

<u>Electromagnetics through the Finite Element Method</u> José Roberto Cardoso,2016-10-03 Shelving Guide Electrical Engineering Since the 1980s more than 100 books on the finite element method have been published making this numerical method the most popular The features of the finite element method gained worldwide popularity due to its flexibility for simulating not only any kind of physical phenomenon described by a set of differential equations but also for the possibility of simulating non linearity and time dependent studies Although a number of high quality books cover all subjects in engineering problems none of them seem to make this method simpler and easier to understand This book was written with the goal of simplifying the mathematics of the finite element method for electromagnetic students and professionals relying on the finite element method for solving design problems Filling a gap in existing literature that often uses complex mathematical formulas Electromagnetics through the Finite Element Method presents a new mathematical approach based on only direct integration of Maxwell s equation This book makes an original scholarly contribution to our current understanding of this important numerical method *Integral Methods in Low-Frequency Electromagnetics* Pavel Solin,Ivo Dolezel,Pavel Karban,Bohus Ulrych,2009-08-11 A modern presentation of integral methods in low frequency

electromagnetics This book provides state of the art knowledge on integral methods in low frequency electromagnetics Blending theory with numerous examples it introduces key aspects of the integral methods used in engineering as a powerful alternative to PDE based models Readers will get complete coverage of The electromagnetic field and its basic characteristics An overview of solution methods Solutions of electromagnetic fields by integral expressions Integral and integrodifferential methods Indirect solutions of electromagnetic fields by the boundary element method Integral equations in the solution of selected coupled problems Numerical methods for integral equations All computations presented in the book are done by means of the authors own codes and a significant amount of their own results is included At the book s end they also discuss novel integral techniques of a higher order of accuracy which are representative of the future of this rapidly advancing field Integral Methods in Low Frequency Electromagnetics is of immense interest to members of the electrical engineering and applied mathematics communities ranging from graduate students and PhD candidates to researchers in academia and practitioners in industry   <u>Finite Element Analysis</u> Farzad Ebrahimi,2012-10-10 In the past few decades the Finite Element Method FEM has been developed into a key indispensable technology in the modeling and simulation of various engineering systems The present book reports on the state of the art research and development findings on this very broad matter through original and innovative research studies exhibiting various investigation directions of FEM in electrical civil materials and biomedical engineering This book is a result of contributions of experts from international scientific community working in different aspects of FEM The text is addressed not only to researchers but also to professional engineers students and other experts in a variety of disciplines both academic and industrial seeking to gain a better understanding of what has been done in the field recently and what kind of open problems are in this area   **A Least-squares Finite Element Method for Electromagnetic Scattering Problems** Jie Wu,1996   *Field Theory Concepts* Adolf J. Schwab,2012-12-06 Field Theory Concepts is a new approach to the teaching and understanding of field theory Exploiting formal analo gies of electric magnetic and conduction fields and introducing generic concepts results in a transparently structured electomagnetic field theory Highly illustrative terms alloweasyaccess to the concepts of curl and div which generally are conceptually demanding Emphasis is placed on the static quasistatic and dynamic nature of fields Eventually numerical field calculation algorithms e g Finite Element method and Monte Carlo method are presented in a concise yet illustrative manner   **Partial Differential Equations and the Finite Element Method** Pavel Ŝolín,2005-12-16 A systematic introduction to partial differential equations and modern finite element methods for their efficient numerical solution Partial Differential Equations and the Finite Element Method provides a much needed clear and systematic introduction to modern theory of partial differential equations PDEs and finite element methods FEM Both nodal and hierachic concepts of the FEM are examined Reflecting the growing complexity and multiscale nature of current engineering and scientific problems the author emphasizes higher order finite element methods such as the spectral or hp

FEM A solid introduction to the theory of PDEs and FEM contained in Chapters 1 4 serves as the core and foundation of the publication Chapter 5 is devoted to modern higher order methods for the numerical solution of ordinary differential equations ODEs that arise in the semidiscretization of time dependent PDEs by the Method of Lines MOL Chapter 6 discusses fourth order PDEs rooted in the bending of elastic beams and plates and approximates their solution by means of higher order Hermite and Argyris elements Finally Chapter 7 introduces the reader to various PDEs governing computational electromagnetics and describes their finite element approximation including modern higher order edge elements for Maxwell s equations The understanding of many theoretical and practical aspects of both PDEs and FEM requires a solid knowledge of linear algebra and elementary functional analysis such as functions and linear operators in the Lebesgue Hilbert and Sobolev spaces These topics are discussed with the help of many illustrative examples in Appendix A which is provided as a service for those readers who need to gain the necessary background or require a refresher tutorial Appendix B presents several finite element computations rooted in practical engineering problems and demonstrates the benefits of using higher order FEM Numerous finite element algorithms are written out in detail alongside implementation discussions Exercises including many that involve programming the FEM are designed to assist the reader in solving typical problems in engineering and science Specifically designed as a coursebook this student tested publication is geared to upper level undergraduates and graduate students in all disciplines of computational engineeringand science It is also a practical problem solving reference for researchers engineers and physicists   Scientific and Technical Aerospace Reports ,1994
    Electric and Magnetic Fields R. Belmans,A. Nicolet,2012-12-06 This book contains the edited versions of the papers presented at the Second International Workshop on Electric and Magnetic Fields held at the Katholieke Universiteit van Leuven Belgium in May 1994 This Workshop deals with numerical solutions of electromagnetic problems in real life applications The topics include coupled problems thermal mechanical electric circuits CAD CAM applications 3D eddy current and high frequency problems optimisation and application oriented numerical problems This workshop was organised jointly by the AIM Association of Engineers graduated from de Montefiore Electrical Institute together with the Departments of Electrical Engineering of the Katholieke Universiteit van Leuven Prof R Belmans the University of Gent Prof J Melkebbek and the University of Liege Prof W Legros These laboratories are working together in the framework of the Pole d Attraction Interuniversitaire Inter University Attractie Pole 51 on electromagnetic systems led by the University of Liege and the research work they perform covers most of the topics of the Workshop One of the principal aims of this Workshop was to provide a bridge between the electromagnetic device designers mainly industrialists and the electromagnetic field computation developers Therefore this book contains a continuous spectrum of papers from application of electromagnetic models in industrial design to presentation of new theoretical developments   *CIM Handbook* M. Mesina,Wilfried J. Bartz,Elmar Wippler,2014-05-15 CIM Handbook The Opportunities for Rationalisation Opened Up by the Acquisition and

Integration of Computer Automation aims to help everyone responsible for structuring computer integrated manufacturing CIM concepts and for procuring and selecting CIM components to find the solutions which meet their requirements in an optimal way as well as having scope for future development The significance of the most important individual CIM packages their function the increase in efficiency to be obtained by their implementation and the prerequisites for their integration in a total CIM concept will all be clearly set out in this book The book begins with a discussion of CIM and the increasing competition faced by companies in both domestic and international markets This is followed by separate chapters on the most important CIM packages the basic prerequisites of CIM namely local networks and databases the implementation of CIM projects and CIM concepts for the middle order companies The final chapter describes the successful implementation of an automated assembly provisioning system in the car industry   Electromagnetic Modeling by Finite Element Methods João Pedro A. Bastos,Nelson Sadowski,2003-04-01 Unlike any other source in the field this valuable reference clearly examines key aspects of the finite element method FEM for electromagnetic analysis of low frequency electrical devices The authors examine phenomena such as nonlinearity mechanical force electrical circuit coupling vibration heat and movement for applications in the elect   **Theory and Computation of Electromagnetic Fields** Jian-Ming Jin,2015-08-26 Reviews the fundamental concepts behind the theory and computation of electromagnetic fields The book is divided in two parts The first part covers both fundamental theories such as vector analysis Maxwell s equations boundary condition and transmission line theory and advanced topics such as wave transformation addition theorems and fields in layered media in order to benefit students at all levels The second part of the book covers the major computational methods for numerical analysis of electromagnetic fields for engineering applications These methods include the three fundamental approaches for numerical analysis of electromagnetic fields the finite difference method the finite difference time domain method in particular the finite element method and the integral equation based moment method The second part also examines fast algorithms for solving integral equations and hybrid techniques that combine different numerical methods to seek more efficient solutions of complicated electromagnetic problems Theory and Computation of Electromagnetic Fields Second Edition Provides the foundation necessary for graduate students to learn and understand more advanced topics Discusses electromagnetic analysis in rectangular cylindrical and spherical coordinates Covers computational electromagnetics in both frequency and time domains Includes new and updated homework problems and examples Theory and Computation of Electromagnetic Fields Second Edition is written for advanced undergraduate and graduate level electrical engineering students This book can also be used as a reference for professional engineers interested in learning about analysis and computation skills   **Innovations in Electrical and Electronic Engineering** Margarita N. Favorskaya,Saad Mekhilef,Rajendra Kumar Pandey,Nitin Singh,2020-07-25 The book is a compilation of selected papers from 2020 International Conference on Electrical and Electronics Engineering ICEEE 2020 held in National Power Training Institute HQ Govt of India on February

21 22 2020 The work focuses on the current development in the fields of electrical and electronics engineering like power generation transmission and distribution renewable energy sources and technology power electronics and applications robotics artificial intelligence and IoT control and automation and instrumentation electronics devices circuits and systems wireless and optical communication RF and microwaves VLSI and signal processing The book is beneficial for readers from both academia and industry   Models and Simulations of the Electric Field in Deep Brain Stimulation Fabiola Alonso,2018-09-10 Deep brain stimulation DBS is an established surgical therapy for movement disorders such as Parkinson s disease PD and essential tremor ET A thin electrode is implanted in a predefined area of the brain with the use of stereotactic neurosurgery In the last few years new DBS electrodes and systems have been developed with possibilities for using more parameters for control of the stimulation volume In this thesis simulations using the finite element method FEM have been developed and used for investigation of the electric field EF extension around different types of DBS lead designs symmetric steering and stimulation modes voltage current The electrode surrounding was represented either with a homogeneous model or a patient specific model based on individual preoperative magnetic resonance imaging MRI The EF was visualized and compared for different lead designs and operating modes In Paper I the EF was quantitatively investigated around two lead designs 3389 and 6148 simulated to operate in voltage and current mode under acute and chronic time points following implantation Simulations showed a major impact on the EF extension between postoperative time points which may explain the clinical decisions to change the stimulation amplitude weeks after implantation In Paper II the simulations were expanded to include two leads having steering function 6180 Surestim1 and patient specific FEM simulations in the zona incerta It was found that both the heterogeneity of the tissue and the operating mode influence the EF distribution and that equivalent contact configurations of the leads result in similar EF The steering mode presented larger volumes in current mode when using equivalent amplitudes Simulations comparing DBS and intraoperative stimulation test using a microelectrode recording MER system Paper III showed that several parallel MER leads and the presence of the non active DBS contacts influence the EF distribution and that the DBS EF volume can cover but also extend to other anatomical areas Paper IV introduces a method for an objective exploitation of intraoperative stimulation test data in order to identify the optimal implant position in the thalamus of the chronic DBS lead Patient specific EF simulations were related to the anatomy with the help of brain atlases and the clinical effects which were quantified by accelerometers The first results indicate that the good clinical effect in ET is due to several structures around the ventral intermediate nucleus of the thalamus   **Numerical Methods for Energy Applications** Naser Mahdavi Tabatabaei,Nicu Bizon,2021-03-22 This book provides a thorough guide to the use of numerical methods in energy systems and applications It presents methods for analysing engineering applications for energy systems discussing finite difference finite element and other advanced numerical methods Solutions to technical problems relating the application of these methods to energy systems are also

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