

# Mathematical Modeling of Eddy Current Non-Destructive Testing

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**Abstract**—This paper proposes analytical and numerical models for the measurement process of Eddy-Current (EC) non-destructive testing. EC inspection represents an essential method for the electromagnetic nondestructive evaluation (NDE) of cracks in conductive materials, with its main applications being found in the examination of aircraft, particle accelerators, and other engineering constructions. The method is based on the detection of the magnetic field produced by eddy currents induced in the specimens being tested. The presence of a crack disturbs the flow of the eddy currents, thus producing a magnetic field perturbation dependent on the position and shape of the defect itself. Variations in the electrical conductivity and magnetic permeability of the test object material, and the presence of defects in the object causes a change in eddy current and a corresponding change in phase and amplitude that can be detected by measuring the impedance changes in the magnetic field generating coil, which is a telltale sign of the presence of defects. The nature of the method is complex and there is therefore a need for deeper understanding that may be gained from mathematical models. Such models can have several objectives as for example procedure and equipment optimization or understanding of the method capability and reliability.

**Keywords**—eddy current testing, mathematical modelling, analytical model, numerical model

## I. INTRODUCTION

EC non-destructive testing is widely used in metal industry and science in order to evaluate the properties of materials without causing damage. This testing method is used in the maintenance of aircrafts, of particle accelerators etc. for: crack detection, conductivity measurements, coating evaluations, material thickness [1]. The phenomenon behind the eddy testing consists in an alternating current flowing through a coil at a chosen frequency, current that generates a time varying magnetic field around the coil as in Fig. 1. When the coil is placed close to an electrically conductive material, eddy currents are induced in the material. If there is a defect in the conductive material, the eddy currents circulation is disturbed and the magnetic coupling between the coil and the tested material is modified and a defect signal can be read by measuring the coil impedance variation [2], [1].

Mathematical models [3], [4] of the physical mechanism of EC inspection are necessary not only for a deeper understanding of the process but also for good results regarding equipments design [5].

This paper proposes a numerical model of the measurement process of EC non-destructive testing which will be validated by an analytical solution.

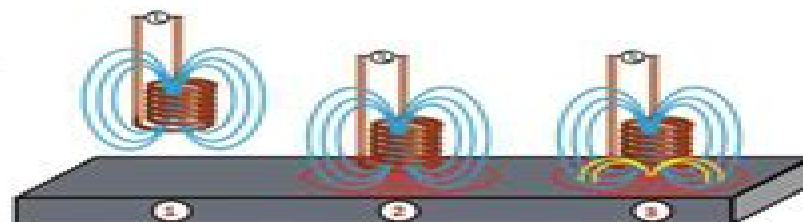


Fig. 1: EC non-destructive testing [6]

## II. ANALYTICAL MODEL

The geometry of the analytical model is the one presented in Fig. 2. The geometrical model consists of one copper winding placed above a conductive plate at a distance  $l$ . This winding is circulated by an alternating current [2].

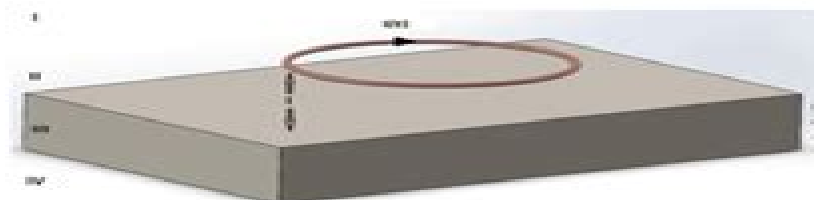


Fig. 2: Single turn coil

The analytical model starts from the Maxwell equations from which the diffusion equation is obtained for the magnetic

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**Auteliano Santos Jr.**



## **Mathematical Modelling In Non Destructive Testing:**

**Mathematical Modelling in Non-destructive Testing** Michael Blakemore, George A. Georgiou, 1988 Very Good No Highlights or Markup all pages are intact

**Mathematical Models, Methods and Applications** Abul Hasan Siddiqi, Pammy Manchanda, Rashmi Bhardwaj, 2015-12-14 The present volume contains invited talks of 11th biennial conference on Emerging Mathematical Methods Models and Algorithms for Science and Technology The main message of the book is that mathematics has a great potential to analyse and understand the challenging problems of nanotechnology biotechnology medical science oil industry and financial technology The book highlights all the features and main theme discussed in the conference All contributing authors are eminent academicians scientists researchers and scholars in their respective fields hailing from around the world *British Journal of Non-destructive Testing*, 1994

**Non-Destructive Testing of Structures** Magdalena Rucka, 2021-02-16 The Special Issue Non Destructive Testing of Structures has been proposed to present the recent developments in the field of the diagnostics of structural materials and components in civil and mechanical engineering The papers highlighted in this editorial concern various aspects of non invasive diagnostics including such topics as the condition assessments of civil and mechanical structures and the connections of structural elements the inspection of cultural heritage monuments the testing of structural materials structural health monitoring systems the integration of non destructive testing methods advanced signal processing for the non destructive testing of structures NDT damage detection and damage imaging as well as modeling and numerical analyses for supporting structural health monitoring SHM systems

**Improving the Effectiveness and Reliability of Non-Destructive Testing** W.E. Gardner, 2013-10-22 This book is concerned with the two most important aspects of the use of non destructive testing Firstly the effectiveness of procedures to detect and size the defects present irrespective of the geometry materials involved or environment Secondly the reliability of instrumentation and personnel to perform the specified procedures Validation and certification techniques required for the justification of safe operation of a plant are also discussed Experts in industries where safety and defect detection are of paramount importance have made valuable contributions drawn from their experience to make this book essential reading for anyone responsible for safety of plant operation Illustrated throughout the book is also of interest to mechanical and structural engineers researchers and inspectors as well as being a useful reference tool for graduate students

Emerging Technologies in Non-Destructive Testing V Alkiviadis S. Paipetis, Theodore E. Matikas, Dimitrios G. Aggelis, Danny Van Hemelrijck, 2012-01-26 Non destructive evaluation NDE methods have dominated most of the fields of applied research and technology over the last twenty years These techniques provide information on the functional efficiency of materials and structures without causing any structural impact on the structure itself Their use enables the monitoring of the structural inte

**Electromagnetic Non-Destructive Evaluation (XXIII)** G.Y. Tian, B. Gao, 2020-11-03 Electromagnetic Non destructive Evaluation ENDE is an invaluable non invasive diagnostic tool for the

inspection testing evaluation and characterization of materials and structures It has now become indispensable in a number of diverse fields ranging from biomedics to many branches of industry and engineering This book presents the proceedings of the 24th International Workshop on Electromagnetic Nondestructive Evaluation held in Chengdu China from 11-14 September 2019 The 38 peer reviewed and extended contributions included here were selected from 45 original submissions and are divided into 7 sections eddy current testing and evaluation advanced sensors analytical and numerical modeling material characterization inverse problem and signal processing artificial intelligence in ENDE and industrial applications of ENDE The papers cover recent studies concerning the progress and application of electromagnetic EM fields in the non destructive examination of materials and structures and topics covered include evaluations at a micro structural level such as correlating the magnetic properties of a material with its grain structure and a macroscopic level such as techniques and applications for EM NDT Recent developments and emerging materials such as advanced EM sensors multi physics NDT intelligent data management and maintaining the integrity of structures are also explored The book provides a current overview of developments in ENDE and will be of interest to all those working in the field

*Non-Destructive Testing of Fibre-Reinforced Plastics Composites* J. Summerscales, 1990-09-30

*Nondestructive Testing of Materials* Roy Collins, 1995

This book reviews the current state of all types of electromagnetic testing techniques and considers the implications of innovations for future inspection practice both in Europe and Japan This volume provides researchers with an overview of exchanges on the subjects of ACPD and ACFM from both Japanese and continental perspectives For instance the Japanese project of applied electromagnetic theory to inspect nuclear power plants and the theory of signal inversion for flaw identification Topics covered are Inversion imaging and flaw reconstruction Advanced signal processing Artificial intelligence and neural networks Modelling simulation and benchmark problems Reliability of inspections new techniques and novel sensors Automation of data acquisition and processing The work covers a wide range of disciplines and will therefore serve a large number of researchers of electromagnetic theory for the next millennium

*Aeronautical Applications of Non-destructive Testing* Abbas Fahr, 2013-12-05

Comprehensive guide to the basic principles and applications of non destructive testing methods for aircraft system and components airframe propulsion landing gear and more Provides detailed analysis of the advantages and disadvantages of major NDT methods Important for design inspection maintenance repair corrosion protection and safety This critical book is among the first to provide a detailed assessment of non destructive testing methods for the many materials and thousands of parts in aircraft It describes a wide variety of NDT techniques and explains their application in the evaluation and inspection of aerospace materials and components ranging from the entire airframe to systems and subsystems At the same time the book offers guidance on the information derived from each NDT method and its relation to aircraft design repair maintenance and overall safety The book covers basic principles as well as practical details of instrumentation procedures and operational results with a full discussion of each method's capabilities

and limitations as these pertain to aircraft inspection and different types of materials e.g. composites and metal alloys. Technologies covered include optical and enhanced optical methods, liquid penetrant replication and magnetic particle inspection, electromagnetic and eddy current approaches, acoustics and ultrasonic techniques, infrared thermal imaging and radiographic methods. A final section is devoted to NDT reliability and ways the probability of detection can be measured to establish inspection intervals.

Electromagnetic Non-Destructive Evaluation (XXI) D. Lesselier, C. Reboud, 2018-05-25

Electromagnetic Nondestructive Evaluation (ENDE) is a technique crucial to a great many engineering activities as well as to environmental evaluation and protection issues. It is a discipline recognized for its theoretical insight, efficient models and simulations, robust data interpretation and accurate instrumentation. This book presents contributions from the 22nd ENDE International Workshop held in Saclay, France, in September 2017. It includes 1 of the 3 keynotes and 34 peer-reviewed and extended versions of the 47 oral contributions delivered during the workshop. Topics covered include static to THz electromagnetic smart models and high performance computations, advanced sensors, adaptive databases, model selection and the qualification of uncertainty, multi-sensor data fusion, the monitoring and diagnosis of mechanical structures and innovative industrial applications. The book will be of interest to all those whose work involves the development or use of electromagnetic non-destructive evaluation.

*Remote Techniques for Nuclear Plant*, 1993. This volume covers the practical application of remote technology to all types of nuclear plant, both experimental and commercial. It concentrates on the remote inspection, refurbishment and decommissioning of reactor pressure vessels, reactor internal components, primary circuits, boiler and steam generators, PWR and fuel routes, reprocessing plant and radioactive waste storage. The emphasis is on equipment currently in use and it also covers equipment under consideration and development. Consisting of 44 papers, these proceedings draw on the experience of nuclear engineers from around the world to form a substantial reference work on remote techniques for the inspection and refurbishment of nuclear plant.

*Proceedings of International Conference on Computational Intelligence* Ritu Tiwari, Mukesh Saraswat, Mario Pavone, 2024-07-17. The book presents high quality research papers presented at International Conference on Computational Intelligence (ICCI) 2023 held at Sardar Vallabhbhai National Institute of Technology, Surat, India, during 4-5 November 2023. The topics covered are artificial intelligence, neural network, deep learning, techniques, fuzzy theory and systems, rough sets, self-organizing maps, machine learning, chaotic systems, multi-agent systems, computational optimization, ensemble classifiers, reinforcement learning, decision trees, support vector machines, hybrid learning, statistical learning, metaheuristics, algorithms, machine vision, Internet of Things, image processing, image segmentation, data clustering, sentiment analysis, big data, computer networks, signal processing, supply chain management, web and text mining, distributed systems, bioinformatics, embedded systems, expert system, forecasting, pattern recognition, planning and scheduling, time series analysis, human-computer interaction, web mining, natural language processing, multimedia systems and quantum computing.

Encyclopaedia of Mathematics Michiel Hazewinkel, 2012-12-06

This is the second supplementary volume to Kluwer's highly acclaimed eleven volume Encyclopaedia of Mathematics. This additional volume contains nearly 500 new entries written by experts and covers developments and topics not included in the previous volumes. These entries are arranged alphabetically throughout and a detailed index is included. This supplementary volume enhances the existing eleven volumes and together these twelve volumes represent the most authoritative comprehensive and up to date Encyclopaedia of Mathematics available. **U.S. Government Research Reports**, 1964

**Handbook of Mathematical Models and Algorithms in Computer Vision and Imaging** Ke Chen, Carola-Bibiane Schönlieb, Xue-Cheng Tai, Laurent Younes, 2023-02-24. This handbook gathers together the state of the art on mathematical models and algorithms for imaging and vision. Its emphasis lies on rigorous mathematical methods which represent the optimal solutions to a class of imaging and vision problems and on effective algorithms which are necessary for the methods to be translated to practical use in various applications. Viewing discrete images as data sampled from functional surfaces enables the use of advanced tools from calculus functions and calculus of variations and nonlinear optimization and provides the basis of high resolution imaging through geometry and variational models. Besides optimization naturally connects traditional model driven approaches to the emerging data driven approaches of machine and deep learning. No other framework can provide comparable accuracy and precision to imaging and vision. Written by leading researchers in imaging and vision the chapters in this handbook all start with gentle introductions which make this work accessible to graduate students. For newcomers to the field the book provides a comprehensive and fast track introduction to the content to save time and get on with tackling new and emerging challenges. For researchers exposure to the state of the art of research works leads to an overall view of the entire field so as to guide new research directions and avoid pitfalls in moving the field forward and looking into the next decades of imaging and information services. This work can greatly benefit graduate students, researchers and practitioners in imaging and vision, applied mathematicians, medical imagers, engineers and computer scientists. **Ultrasonic Waves** Auteliano Santos Jr., 2012-03-07. Ultrasonic waves are well known for their broad range of applications. They can be employed in various fields of knowledge such as medicine, engineering, physics, biology, materials etc. A characteristic presented in all applications is the simplicity of the instrumentation involved even knowing that the methods are mostly very complex, sometimes requiring analytical and numerical developments. This book presents a number of state of the art applications of ultrasonic waves developed by the main researchers in their scientific fields from all around the world. Phased array modelling, ultrasonic thrusters, positioning systems, tomography, projection gas hydrate bearing sediments and Doppler Velocimetry are some of the topics discussed which together with materials characterization, mining corrosion and gas removal by ultrasonic techniques form an exciting set of updated knowledge. Theoretical advances on ultrasonic waves analysis are presented in every chapter especially in those about modelling the generation and propagation of waves and the influence of Goldberg's number on approximation for finite amplitude acoustic waves. Readers

will find this book a valuable source of information where authors describe their works in a clear way basing them on relevant bibliographic references and actual challenges of their field of study Non-Destructive Testing And Evaluation For Manufacturing And Construction. H. Dos Reis,1989-12-01 Exploring advances and strengthening communications among researchers in manufacturing and construction technologies this book covers nondestructive testing and evaluation methods Drawing on a wide range of experts it provides insights from every sector of the field Based on a three day conference titled Nondestructive Testing and Evaluation for Manufacturing and Construction held on the campus of the University of Illinois at Urbana Champaign the papers presented in the book foster development of new and innovative methods **Technical Abstract Bulletin** ,1964 Non-Destructive Evaluation of Reinforced Concrete Structures Christiane Maierhofer,Hans-Wolf Reinhardt,Gerd Dobmann,2010-06-04 Many concrete structures and elements of concrete infrastructure have exceeded their original design lives and are deteriorating to an extent where they are becoming dangerous The deterioration can be internal or not obvious and therefore only shows up with detailed testing Non destructive evaluation of reinforced concrete structures Volume 1 Deterioration processes and standard test methods reviews the processes of deterioration and classical and standard test methods Part one discusses deterioration of reinforced concrete and testing problems with chapters on topics such as key issues in the non destructive testing of concrete structures when to use non destructive testing of reinforced concrete structures deterioration processes in reinforced concrete modelling ageing and corrosion processes in reinforced concrete structures components in concrete and their impact on quality and predicting the service life of reinforced concrete structures Part two reviews classical and standard testing methods including microscopic examination of deteriorated concrete the analysis of solid components and their ratios in reinforced concrete structures the determination of chlorides in concrete structures and investigating the original water content of reinforced concrete structures With its distinguished editors and international team of contributors Non destructive evaluation of reinforced concrete structures Volume 1 Deterioration processes and standard test methods will be a standard reference for civil and structural engineers as well as those concerned with making decisions regarding the safety of reinforced concrete structures Provides a comprehensive discussion from examination of the components in concrete and their affect on quality through to the role of and tools required for lifetime management Experts in the field identify the testing problems associated with infrastructure considering design build and maintenance stages Presents a guide for when to use non destructive testing of reinforced concrete structures including the role of time in testing

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