

# 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.

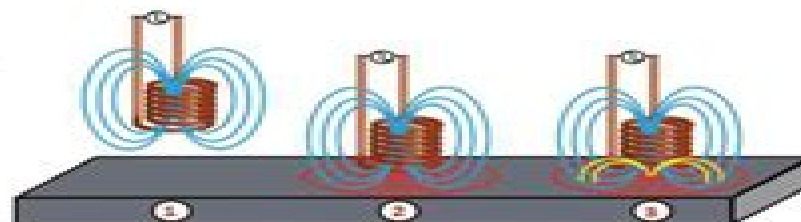


Fig. 1: EC non-destructive testing [6]

## 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].

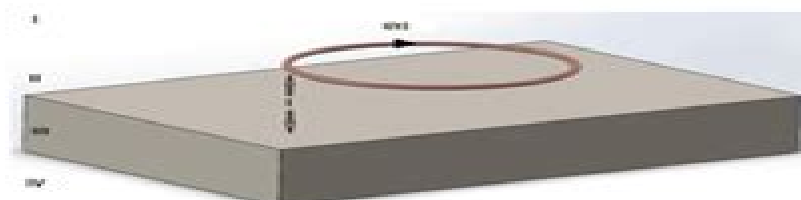


Fig. 2: Single turn coil

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

# Mathematical Modelling In Non Destructive Testing

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## **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      **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      **British Journal of Non-destructive Testing** ,1994

**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

Electromagnetic Non-Destructive Evaluation (XXIII) Bin Gao, 2020-11-15 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 E Recent developments and emerging materials such as advanced EM sensors multi physics NDT E 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 *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 integrity the structural condition as well as the service induced degradation of materials and structures during their service life In this respect they address a vast field of applications ranging from the aerospace and automotive industry to civil engineering structures and material quality control This volume comprises scientific papers presented during the Fifth Conference on Emerging Technologies in Non Destructive Testing Ioannina Greece 19 21 September 2011 A broad spectrum of related research was presented during the course of the conference including optical acoustic thermal electrical and electromagnetic methods together with imaging tomographic and signal processing techniques Special attention was given to NDE for Civil Engineering Structures and for the first time in the conference series a multiple session on NDE for the protection of cultural heritage was organized Emerging Technologies in Non Destructive Testing V contains contributions by experts in this field from 22 different countries worldwide Reflecting the state of the art in Non Destructive Evaluation the book will prove to be a valuable companion to students engineers and industrial partners who are active in the field of non destructive evaluation and testing This volume will also provide students and researchers with insight into the focal points of contemporary research efforts in the field of non destructive evaluation

*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 millenium

**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

**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

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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

*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 PIE 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

**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 **Barkhausen Noise for Non-destructive Testing and Materials Characterization in Low Carbon Steels** Tu Le Manh, Jose Alberto Perez Benitez, Jose Hiram Espina Hernandez, Jose Manuel Hallen, 2020-06-11 Barkhausen Noise for Nondestructive Testing and Materials Characterization in Low Carbon Steels presents a balanced approach reviewing the disadvantages and advantages of using this technique and its comparison over other magnetic testing techniques In addition the book looks towards future applications of this technique in particular its industrial applications as a method for pipeline inspection current advantages and barriers to implementation The book is suitable for materials scientists researchers and engineers and may be applicable for those working in metallurgical plants Not only does the book discuss fundamentals it reviews recent discoveries such as the correlation between magnetocrystalline energy and Barkhausen noise the modeling of this relationship and the application of this technique in the characterization of magnetic materials Provides detailed explanation for the stochastic and deterministic characteristics of Barkhausen noise Discusses principles of applying Barkhausen noise as a non destructive method and magnetic material characterization method Reviews the advantages and disadvantages of this non destructive testing technique and compares it to other competitive techniques

*The Application of Mathematics in Industry* R.S. Anderssen, F.R. de Hoog, 2013-04-17 This publication reports the proceedings of a one day seminar on The Application of Mathematics in Industry held at the Australian National University on Wednesday December 3 1980 It was organized jointly by the Division of Mathematics and Statistics CSIRO and the Departments of Pure and Applied Mathematics The Faculty of Science Australian National University A paper based on the talk Some uses of statistically designed experiments in industrial problems given by N B Carter at the Seminar was not received by the editors Though R M Lewis of John Lysaght Australia Limited did not present a talk the editors invited him to submit a paper They only learnt about his work after the program for the seminar had been finalized and publicized His paper appears as the last paper in these proceedings and is entitled A simple model for coil interior temperature prediction during batch annealing The seminar was opened by Dr J R Philip FAA FRS Director of the Physical Sciences Institute CSIRO He kindly agreed to supply an edited version of his comments for inclusion in the proceedings They follow the Foreword as Opening Remarks **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

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