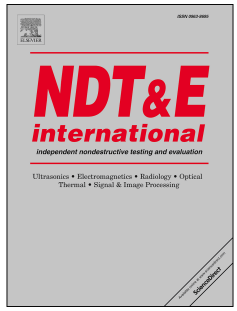

Study of the non-linear eddy-current response in a ferromagnetic plate: Theoretical analysis for the 2D case

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Study of the non-linear eddy-current response in a ferromagnetic plate: theoretical analysis for the 2D case

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Abstract

The non-linear induction problem in an infinite ferromagnetic pate is studied theoretically by means of the truncated region eigenfunction expansion (TREE) for the 2D case. The non-linear fromulation is linearised using a fixed-point iterative scheme, and the solution of the resulting linear problem is constructed in the Fourier domain following the TREE formalism. The calculation is carried out for the steady-state response under harmonic excitation and the harmonic distortion is derived from the obtained spectrum. This article is meant to be the theoretical part of a study, which will be complemented by the corresponding experimental work in a future communication.

Keywords: electromagnetics, non-linear modelling, modal methods, ferromagnetic materials.
PACS: 02, 41

1. Introduction

In material characterization applications, the tested specimen is subject to a strong electromagnetic field in order to trigger its non-linear behaviour. The main interest in these techniques relies on the fact that the magnetic properties of ferromagnetic media, especially their hysteretic characteristics, are strongly related to their microstructure, and hence they provide an indirect link for the assessment of properties like mechanical strength, presence of residual stresses, etc., which are usually accessible through destructive tests or other complicated and expensive techniques.

In case of planar specimens like strips or plates, the two main methods for establishing the excitation field are using air-cored coils, located above or at both sides of the piece, or via a closed magnetic circuit (yoke), which is brought in contact with the specimen interface.

The simulation of the inspection procedure with either methods requires the solution of a non-linear, hysteretic problem. The standard way of treating this problem is via successive linearisation using either the fixed-point method (also known as polarization or Picard-Banach method) or the Newton-Raphson scheme and the application of a numerical technique for the solution of the resulting linear problem at each iteration. Considerable progress has been made the past years in the development of such solvers based on the finite elements method (FEM), the finite integration technique (FIT) [1, 2, 3, 4, 5] or the integral equation approach [6, 7, 8]. The relevant literature is vast, and the above list should be understood only as indicative.

The main inconvenience in using these techniques is that they rely on the application of a volume mesh, with a large number of degrees of freedom (dofs), which results in the repeated inversion of a large (sparse or full, depending on the formulation) system of linear equations. To overcome this drawback, sophisticated techniques using semi-explicit schemes for the minimization of linear system inversions have been proposed [4, 5]. Another approach to cope with the raised computational effort is to resort to hardware acceleration e.g. using parallel and/or GPU adapted implementations [8]. An additional difficulty is linked with the existence of steep field gradients inside the ferromagnetic materials, which raise increased demands in terms of grid resolution, thus reducing the robustness of the solution and making human expertise indispensable in order to assure the validity of the results.

The above mentioned drawbacks can be partly avoided if we are willing to sacrifice the versatility of generic numerical solvers for the favour of more case-dependant modal approaches. Indeed, since the majority of eddy-current inspection/evaluation configurations involve relatively simple geometries that are amenable to semi-analytical solutions, this approach can be a valuable aid to the analysis, owing to the very convenient computational times and the absence of a computational mesh[1].

In this article, the non-linear eddy-current response of an infinite ferromagnetic plate to two coaxial air-cored cylindrical coils located at its both sides will be studied by

[1]In the case of the non-linear solver, the spatial discretization of the magnetisation cannot be avoided, yet the mesh used for its evaluation is restricted inside the ferromagnetic material, and it impacts the solution only indirectly as it will become clear by the analysis.