Eddy current analytical calculation under low frequency AC magnetic field

Yasmine Gabi [a,b], David Böttger[b], Bernd. Wolter[c]

ª Fraunhofer Institute for non-destructive testing IZFP, Campus E3 1, Saarbrücken, Germany.
ᵇChair of Cognitive Sensor Systems, Saarland University, Fraunhofer IZFP, Campus E3 1, Saarbrücken, Germany

The paper deals about the simulation of linear and non-linear eddy current (EC) techniques in the commercial 3MA NDT systems. Robust analytical computation is established to investigate the properties of bilayer specimens. In non-linear EC, the quasi-static magnetic behaviour is described via the Jiles-Atherton model. In order to take into account the dynamic phenomena, the model is extended to Berttoti formula. Based on electromagnetic meso-macroscopic behaviour, the experimental signals are accurately reproduced. The impact of frequencies and surface layer thickness are analysed experimentally and numerically.

Keywords: conventional eddy current calculation; magnetic hysteresis behaviour; nonlinear eddy current

1. Introduction

The design and construction of specialized Non Destructive Evaluation (NDE) equipment, in-process monitoring remains crucial for the quality control in European industry. It may be supported via robust calculation tools, in order to optimize the inspection situation to determine the requested measuring metrological quantities, such as coating, hardness, residual stress, etc. The emerging use of numerical simulation is a major trend in the field with tremendous potential benefits in terms of costs reduction, enhanced diagnosis reliability and consequently increased competitiveness. The simulation of 3MA electromagnetic methods attracked attention of many experts. Some of them works on development on complete robust physical based models in order to simulate the several 3MA magnetic methods like Eddy current [1], harmonic analysis and incremental permeability (IP) [2].

These models rely on parametric descriptions of some fundamental electromagnetic properties of different specimen layers, e. g. electrical conductivity and hysteresis law, describing the magnetization, like saturation polarization or initial magnetic permeability or most favourable the complete parameterised B/H hysteresis loop. In 2012, an analytical calculation of eddy current 3MA method was investigated in framework of ANR DPSMMOD project. The purpose was to describe the magnetic signature of 3MA eddy current and incremental permeability (see Fig.1). Gabi and all have developed an analytical model for conventional eddy current investigation [3].

2. Analytical eddy current model

The model targets qualitative goal based on simplified aspects, considering a finite sized ferromagnetic samples and the detection coil has a cylindrical geometry. Furthermore, it is supposed that a global demagnetizing coefficient influences the amplitude of the field in the different zones (layers) of the sample but not on the direction. Considering these strong simplifications, the solving problem became 1D. The model was validated for conventional linear EC in the inspection of dual phase steel [4].

Figure 1: 3MA NDT system under test.

In the following work, the EC analytical model is extended in order to take into account the non-linear aspect of ferromagnetic material at higher magnetization level by integration of incremental permeability, computed via Jiles-Atherton hysteresis model. Adding to this, the dynamic phenomena is described via Berttoti formula. The assessment of the 3MA non-linear EC (IP) is performed by comparison of computed data and experimental signals

References

[1] K. Sidi-Ahmed, B. Maouche, Y. Gabi, L. Alloui, B. Straß, B. Wolter, M. Feliachi, Numerical simulations and experimental investigation of laser hardening depth investigation via 3MA-eddy current technique, JMMM, Vol 550,2022.
[2]Y. Gabi , D. Böttger , B. Straß , B. Wolter, Ch. Conrad and F. Leinenbac, Local electromagnetic investigations on electrical steel FeSi 3% via 3MA micromagnetic NDT system. 12th ECNDT, Gothunburg, Sweeden, 2018.
[3] Y. Gabi, O. Martins, B. Wolter, and B. Straß, "Combination of electromagnetic measurements and FEM simulations for nondestructive determination of mechanical hardness." AIP Advances, 8 (2018) 047502–047502
[4] Y. Gabi. FEM Modelling of a 3MA Non-destructive Testing System on Line of Production of Dual Phase Steel. Grenoble 27.04.2012. https://tel.archives-ouvertes.fr/tel-00749