Polynomial-Chaos Uncertainty Modeling in Eddy-Current Inspection of Cracks

T. T. Zygiridis[1], A. E. Kyrgiazoglou[2], T. P. Theodoulidis[2]

[1]Department of Informatics and Telecommunications Engineering, University of Western Macedonia, Kozani, Greece
[2]Department of Mechanical Engineering, University of Western Macedonia, Kozani, Greece

Abstract

In the context of non-destructive evaluation methods, eddy-current testing plays a prominent role in crack-detection problems, due to its various attractive features. One of the physical quantities that typically interest us in such type of problems is the - complex - coil impedance and how its value is modified, when a crack is present at its proximity. Evidently, the reliable estimation of the coil impedance change, which depends on a number of problem parameters, is of crucial importance. Till today, however, the majority of pertinent eddy-current studies comply with fully deterministic frameworks, usually neglecting the stochastic character that some of the considered problem's aspects - either geometric or electric - may display.

The purpose of this work is to assess the impact of geometric or other types of uncertainty on the output quantities of representative eddy-current problems with cracks. Common stochastic methodologies are based on the well-known Monte-Carlo (MC) approach, which unfortunately necessitates the execution of a considerable number of simulations, in order to provide convergent statistical information. Here, we aim to reduce the involved computational cost by resorting to polynomial-chaos (PC) theory, and exploiting the potential of sparse-grid integration. Given the stochastic character of this study, the change in the coil's impedance due to the induced eddy currents is treated as a random variable, and approximated with the aid of truncated polynomial series. The latter entails basis functions, directly related to the type of distribution that describes the input random parameters. The necessary expansion coefficients are computed by projecting the series on every basis function, and taking into account their inherent orthogonality property. The appearing inner products need to be computed in an efficient manner; otherwise, no significant improvement over the MC technique can be anticipated. Quadrature based on full (tensor-based) grids can be applied, while integration on sparse (Smolyak) grids can further reduce the number of the necessary integration nodes, without sacrificing accuracy. We conduct tests considering different selections of the one-dimensional quadrature, which the multi-dimensional numerical integration rule is based on, in search for an optimum approach. After the PC representation of the coil impedance has been calculated, statistical measures such as the mean value and the variance can be easily deduced from the expansion coefficients, while additional information can be extracted from probability density functions and Sobol (sensitivity) indices, which are computed from the PC series without difficulty.

The eddy-current simulations necessary to perform this study are based on the finite-element modeling capabilities of the COMSOL Multiphysics® software, utilizing the AC/DC Module. The test cases examined here are narrow cracks, which require a sufficiently refined mesh locally, in order to ensure consistent problem discretization. As the implemented numerical quadrature utilizes sets of specific nodes in the random space that correspond to distinct simulations setups with different input values, we automate calculations by performing properly defined parametric sweep studies. The preliminary results verify the possibility to predict reliably the stochastic properties of eddy-current inspection problems, at a fraction of the computational cost of standard MC studies.

Figures used in the abstract

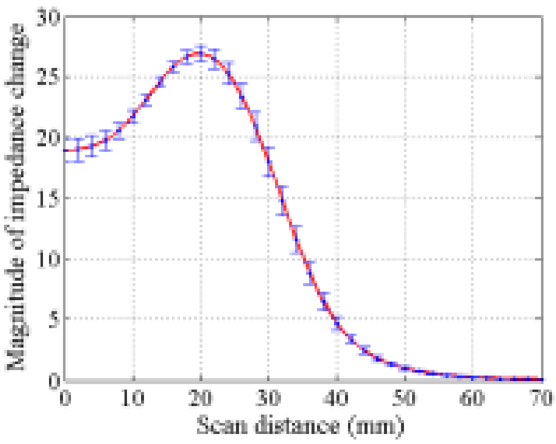

Figure 1: Mean value and standard deviation of coil impedance change versus scan distance.