Diagnosis of Real Cracks from Eddy Current Testing Signals using Parallel Computation

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***Abstract*—This paper presents a novel approach for diagnosis of real cracks from two-dimensional eddy current testing signals by means of a parallelized stochastic method, tabu search. A new testing probe driving uniformly distributed eddy currents is employed for the inspection. Three spatial components of the perturbation field due to partially conductive cracks are sensed as the response signals in order to enhance information level of the inspection. The signals are simulated by a fast forward FEM-BEM solver using a database. The cracks are modeled as defects with a complex shape and uniform conductivity. The length, depths, width and conductivity of the crack are unknown in the inversion process. Numerical results of the 3D reconstruction of partially conductive cracks from simulated 2D signals with added noise are presented and discussed. For the full paper, the measured signals will be used in the inversion process in order to validate the approach.**

***Index Terms*—Computational electromagnetics, eddy currents, inverse problems, parallel programming.**

I. Introduction

Real cracks, such as stress corrosion cracks (SCC), usually appear in steam generator (SG) tubes of pressurized water reactor (PWR) of nuclear power plants. Recently, quite satisfactory results are reported by several groups for automated evaluation of artificial slits [1] and even for several parallel notches [2] using eddy current testing (ECT). However, evaluation of real cracks from ECT signals remains still very difficult. One possible reason is that actual ECT probes do not provide sufficient information [1] resulting from findings that an SCC is partially conductive while its conductivity is not known in general and can vary from one case to another [3].

Several studies of the authors focused on enhancing information level of eddy current testing signals and on decreasing uncertainty in evaluation [4], [5]. Promising results create new challenges concerning development of automatic procedures for diagnosis of real cracks.

The authors have already developed an algorithm for the reconstruction of multiple non-conductive cracks from ECT signals by means of a stochastic optimization method, such as tabu search [2]. The reconstruction of multiple cracks validated by experimental data was a 3D one. Therefore, the scheme is also appropriate for the reconstruction of a partially conductive crack, when the width is not considered as constant. It is well known that the width significantly affects the signal for cracks of non-zero conductivity [6].

The paper proposes a novel approach for the three-dimensional reconstruction of partially conductive cracks from simulated two-dimensional ECT signals, consisting of all the three spatial components of the perturbation field.

II. Approach for Diagnosis of Conductive Cracks

A new eddy-current probe, shown in Fig. 1, is designed for the two-dimensional inspection of a conductive plate. It consists of two circular exciting coils positioned apart from each other and oriented normally concerning the plate's surface. The circular coils are connected in series but magnetically opposite to induce uniformly distributed eddy currents. The eddy current response signals are sensed by three AMR magnetic sensors. The three sensors are oriented in such a way that they sense three spatial components of the perturbation field. The detection system is located in the centre between the exciting coils to reduce direct coupling with the exciting system and to gain high sensitivity.

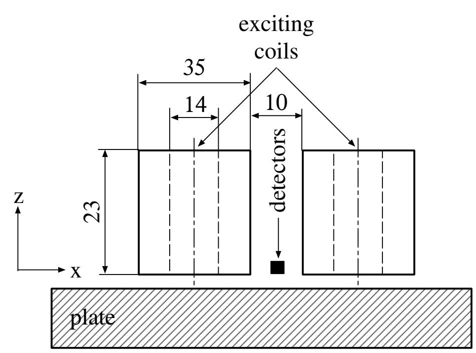

Fig. 1. ECT probe configuration

The fast-forward FEM-BEM analysis solver using database [2] is adopted here for the ECT signals simulation.

The tabu search is applied for the 3D reconstruction of partially conductive cracks [2]. The parallelization programming, OpenMP, is used in the inversion algorithm in order to reduce significantly the computing time. The error function ε to be minimized is defined as:

$$\varepsilon = \sum_{k=x,y,z} \frac{\sum_{i=1}^{n} \left| \Delta V_{ik} - \Delta V_{ik}^{m} \right|^2}{\sum_{i=1}^{n} \left| \Delta V_{ik}^{m} \right|^2}, \quad (1)$$

where ΔV_i and ΔV_i^m are the simulated voltage for the current crack and the voltage measured by the AMR sensors at the i-th scanning point respectively, and n is the number of scanning points. It should be noted that the real and the imaginary parts of each spatial component (X, Y and Z) of the perturbation electromagnetic field are employed for the inversion.

The cracks are modeled as defects with a complex shape (different depths along the length direction), not-fixed width and uniform conductivity, as shown in Fig. 2. The length, depths, width and conductivity of the cracks are unknown in the inversion process of the signals.

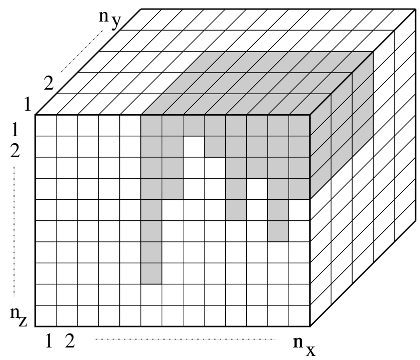

Fig. 2. Crack model: complex shape of the crack

III. Numerical Results and Discussions

Fig. 3 shows the result of three-dimensional diagnosis a partially conductive crack with an elliptical profile. The crack has the following features: the width of 0.4 mm, the surface length of 14 mm, the maximum depth of 4 mm and the conductivity of 8% of the base material conductivity.

The width and length of the crack are accurately assessed. The estimated crack position is minimally shifted (0.4 mm) in the crack width direction comparing the true position. The maximum depth is slightly overestimated of 1 mm.

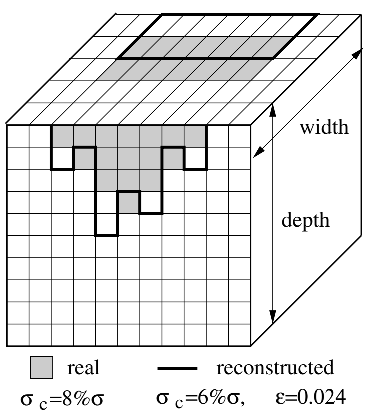

Fig. 3. Reconstruction of a partially conductive crack with an elliptical shape

Fig. 4 shows the results of three-dimensional diagnosis a partially conductive crack (rectangular shape, length of 6 mm, width of 0.8 mm, depth of 4 mm, and conductivity of 5% of the base material conductivity) from 2D ECT signals with added noise of maximum level 20%.

The crack is precisely localized and also its length is exactly estimated. The depth profile does not perfectly copy the true one. However, the maximum depth is accurately assessed. The width is smaller with a minimum value of 0.4 mm than the real width.

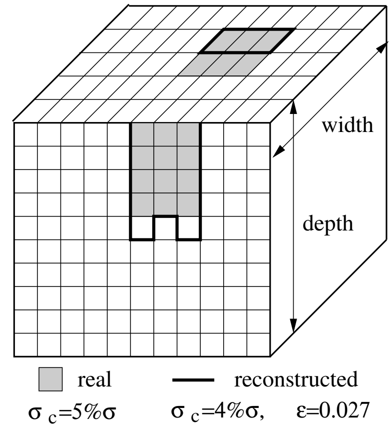

Fig. 4. Reconstruction of a partially conductive crack with a rectangular shape from perturbed signal by added noise of maximum level of 20%

The presented results proved that the proposed approach allows quite precisely reconstructing three-dimensional profile of a crack together with its partial conductivity from signals with added noise.

In the full paper, the validity of the approach will be proved by using measured signals in the inversion process.

IV. Acknowledgements

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