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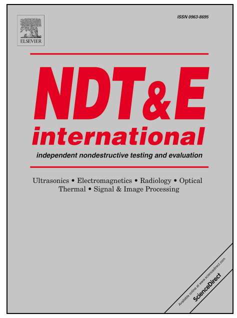

Elastic Net Regularization in Lorentz force evaluation

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Elastic Net Regularization in Lorentz Force Evaluation

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Abstract

Lorentz force evaluation is a nondestructive evaluation method applied for the characterization of sub-surface defects in specimen consisting of layers of conducting material. The movement of a specimen under investigation relative to a permanent magnet leads to Lorentz forces that are perturbed in the presence of a defect. A minimum norm estimation (MNE) with Elastic Net Regularization (ENR) is compared to MNE with Tikhonov-Phillips-Regularization (TPR) regarding the ability to determine defect properties from force perturbation signals. A cylindrically shaped defect with diameter of 5 mm and height of 2 mm is examined at depths of 2, 4 and 8 mm. Simulated data obtained by the finite element method and measured data are considered. ENR and TPR estimated the defect depth correctly for simulation and measurement data at depths of 2 and 4 mm, while at 8 mm, only ENR estimated the depth correctly. The defect sizes were slightly overestimated for both ENR and TPR. TPR produced additional spurious solutions at the boundary of the reconstruction grid. We conclude that ENR is more suitable than TPR for MNE in Lorentz force evaluation.

Keywords: Composite Material, Inverse Problems, Minimum Norm Estimation, Motion Induced Eddy Current Testing, Nondestructive Evaluation

1. Introduction

The increasing requirements for quality and safety of materials and the development of new materials require high-resolution nondestructive evaluation methods during manufacturing and maintenance. In contrast to nondestructive testing, which offers information if there is a failure or not, the nondestructive evaluation characterizes the defect by estimating its size, shape and location. Nowadays, conducting materials or composite materials with conducting layers are evaluated by ultrasonics [1], radiography [2], thermography [3, 4], magnetic induction thermography [5], magnetic flux leakage [6], and eddy current testing [7].

The Lorentz force evaluation (LFE) is a novel technique for the characterization of deep lying defects in the conducting layers of composite materials [8]. LFE is a motion induced eddy current evaluation method, which uses eddy currents induced in the specimen under investigation due to the movement relative to a permanent magnet. The resulting Lorentz forces are perturbed in the presence of a defect and act as input signal for the defect reconstruction. Previous work realized the reconstruction of defect properties by determination of the conductivity distribution using truncated singular value decomposition [8] and the differential evolution [9]. Additionally, current density reconstruction [10] has been applied. Commonly, the defect reconstruction in LFE is performed separately in every metal layer, where the analysis yields a possible defect with a corresponding error for every single layer. This error is defined as the deviation of the Lorentz force perturbation signal obtained from measurements and the forward calculated Lorentz force perturbation. The sheet with the lowest error indicates the defect depth. This procedure assumes that only a single defect is present within the investigated region. In LFE, the force perturbation signals of a small defect near the top surface of the specimen and a larger and deeper defect can be similar. This characterizes the LFE as an ill-posed inverse problem.

It is the aim of the current study to regularize this problem by incorporating additional *a priori* information. We propose the use of a minimum norm estimation with Elastic Net Regularization (ENR) [11] for the estimation of a defect identification vector. ENR leads to an estimated vector with connected values unequal to zero in the defect region surrounded by zeros. This reflects the situation of a defect as a connected structure surrounded by a conductor with constant conductivity. The reconstruction results will be compared to the more widely used Tikhonov-Phillips-Regularization (TPR) [10, 12–14]

First, the ENR and the TPR will be applied to three simulated data sets obtained by the finite element method (FEM). The setup consists of a package of stacked aluminium sheets with three different defect depths. Further, we perform parameter studies on the simulated data sets. Second, ENR and TPR will be applied to measurement data that comprise stacked aluminium sheets with the same defect depths as in the simulations. Third, the repeatability will be investigated by analyzing repeated measurements.

2. Problem setup

2.1. Problem description

A specimen is moved relative to a fixed permanent magnet with the velocity $\boldsymbol{v} = 0.1$ m/s $\boldsymbol{e}_x$ (Fig. 1) along multiple consecutive parallel scanning lines. The interaction of the induced