Stress Zone Imaging in Steel Plates using Multi Coil Array Sensors

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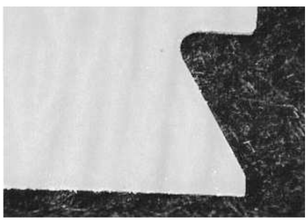
***Abstract*—Stress zones in electrical steel are referred to as parts of steel sheets of electrical machines which have seen severally mechanical stress during the production process of the machine. The mechanical stress (cutting punching, etc.) causes decreased electrical material properties in the active part volumina leading to increased losses. In this paper we will extend the latest developments of stress zone imaging - this is an imaging technique to determine spatial material properties of the sheet by the use coil sensors - towards the use industrial sensors in order to image the properties close to the cutting edge.**

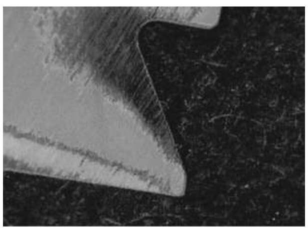
***Index Terms*—Eddy current, inverse problem, optimization, electrical machines, steel**

I. Introduction

By providing the magnetic path for the flux inside electrical machines, steel sheets are the central components of the stator and rotor in any rotating electrical drive. Electro steels are produced in steel companies and provided to the machine factory in form of rolls. Then the parts parts of the stator and the rotor a cut out to obtain the slices of the later machinery parts. During the manufacturing process the steel sheet receives severely mechanical stress due to the different steps of the production process like cutting, punching and bending. These processes effects the electromagnetic properties of the steel sheet in a negative way (increased losses). Figure 1 shows two figures of steel sheets during the production process.



(a) Steel sheet with punching burrs.



(b) Steel sheet with removed punching burrs. Additional isolation is required.

Figure 1. Steel sheet during the production process.

In the works of Nakata [1], Saito [2] and Ossart [3] the effects of stress due to cutting, punching and bending of the sheets are reported. Even the last two production processes showed similar effects as cutting. The significance of this topic is due to the fact, that decreased magnetic properties cause increased iron losses in the active parts volumina of the machine. The impact of these losses (eddy current and hysteresis) even becomes more important to the fact that the power densities steadily increase.

An early method to determine local electromagnetic properties of the sheets was invented by the Austrian E. Werner in the late fifties of the last century [4]. For the so called needle probe method, electric currents are injected into the steel sheet by two needles. A magnetic field probe (i.e. a Hall probe) is used to measure the magnetic field strength at the surface of the steel sheet. As the magnetic properties modulate the field strength at the surface, the sensor signal can be used to quantify the material properties. In 2000 Senda et al. proposed a modified version using several needles. However, as needle probe based systems offer drawbacks like the destruction of the insulation layer. Also the measurement process is of time consuming nature, as these methods only take local measurements.

A contrary model based approach to determine local material parameter deviations in the steel sheets was presented by the authors in 2010 [5]. In this work a coil array was placed above a steel sheet. Figure 2 depicts the simulated arrangement. Using measurements from the coil array an inverse problem [6] is solved, which allows a reconstruction of the spatial material parameters. The work was a simulation feasibility study for stress zone imaging using a coil array.

In this paper we will present further develops on the idea of stress zone imaging using coil array senors and consider the reconstruction of material parameters in the region of the edges of the steel sheet. In contrast to the initial publication presented in [5] we will consider the use of commercial available multi coil array sensors in order to push the development of the sensor system.

A. Idea of the Model based Approach

Model based approaches for solving indirect or inverse measurement problems are based on the use of a computer model, or forward map, $F : \boldsymbol{x} \mapsto \boldsymbol{y}$, $\boldsymbol{x} \in \mathbb{R}^N$, $\boldsymbol{y} \in \mathbb{R}^M$, which simulates the physical measurement process $P : \boldsymbol{x} \mapsto \tilde{\boldsymbol{d}}$. Hereby $\tilde{\boldsymbol{d}} \in \mathbb{R}^M$ are the measurements which are corrupted

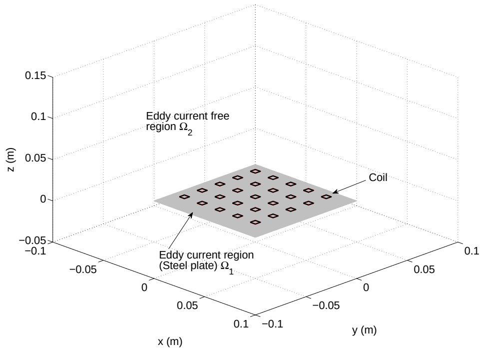


Figure 2. Geometry under investigation in [5] (figure taken from [5]).

by noise. The parameters of interest are summarized into the parameter vector $\boldsymbol{x}$. The measurement problem is to find $\boldsymbol{x}$ given the data $\tilde{\boldsymbol{d}}$. Classical deterministic solution approaches are formed by the way of optimization problems. Typical approaches are given by the form

$$\boldsymbol{\xi}^* = \arg\min_{\boldsymbol{x}} \left\{ \|\boldsymbol{y}(\boldsymbol{x}) - \tilde{\boldsymbol{d}}\|_2^2 + \alpha \|\boldsymbol{R}(\boldsymbol{x})\|_2^2 \right\}. \quad (1)$$

The first term in equation (1) minimizes the data misfit between the measurement $\tilde{\boldsymbol{d}}$ and the model output $\boldsymbol{y}$. The second term is a regularization which is required to stabilize the problem due to its numerical instability caused by its ill-posed nature [8],[5].

The forward map $\boldsymbol{F}$ for solving the inverse problem of stress zone imaging is an eddy current problem which aims on the computation of coil parameters given the geometry and the parameter vector $\boldsymbol{x}$. Various standard approaches for solving the underlying eddy current problem are summarized in [7]. Methods for solving (1) are found in numerical optimization theory [9].

For the physical measurements we consider the use of a an industrial available multi coil probe sensor as depicted in figure **??**. The sensor head delivers the measurements $\tilde{\boldsymbol{d}}$. Such sensor heads were originally developed for non-destructive material testing.

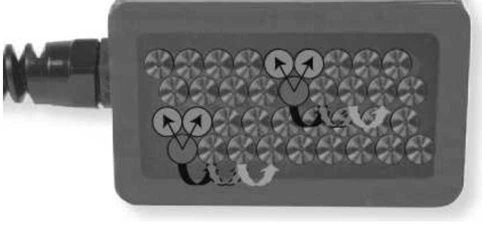


Figure 3. Industrial sensor head offering different coils (picture taken from [10]).

B. Outlook

The final paper will include a detailed description about the use of industrial multi coil array eddy current sensors for stress zone imaging at the cutting edges of steel sheets. The paper will present the results from simulation studies, as well as an analysis of the system properties in order to further develop the measurement system.

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