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Conductive biomaterial inhomogeneities modeling in electromagnetic nondestructive evaluation

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Abstract

A three-dimensional numerical modeling is an appropriate tool for analyzing and estimating of the physical material properties in general. This article is focused on the modeling of inhomogeneities in the austenitic stainless steels, which are used as biomaterials. These materials can interact with a biological tissue inside a human body. In addition, these steels are also widely used in many industry and transport sectors. Three fundamental inhomogeneity models were created for this purpose. The models correspond to the real inhomogeneities that may occur in these materials (fatigue and stress-corrosion cracks). Third model is the artificial one, used as the reference sample. The all models are investigated by the eddy current testing method which is theoretically well-known and described for investigation of conductive biomaterials. The results of numerical simulation are presented and discussed in this paper.

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1. Introduction

A three-dimensional (3D) modeling is an effective tool for predicting and investigation of physical phenomena of studied objects. Possibility of creating of accurate mathematical objects or simplified objects without a distracting elements is a way to their precise description and investigation. Addition to static physical models are widely used

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interactive models that allow changes in the properties of the model during the investigation. It allows to create objects that tends to changing and they simulate real behavior of matter.

In our research, we use the three-dimensional modeling for simulation of non-destructive evaluation (NDE) of austenitic steels. Modeling of the conductive materials is our region of interest. Mainly, the austenitic stainless steel of grade 316L, which is used as a biomaterial in various medical applications and as commercial steel on the field of industry and transport (weld-on transport ring, hygienic pallet transport or motor shielding, etc.). Although, presence of material cracks may affect usability of the steel. The realized experiments and numerical simulation are the necessary procedures to material be investigated.

NDE is a logical step to ensure the quality and functionality of the final products made of biomaterials. The testing, in the first place, protect patients, employers and car drivers, against additional health complications. A biomaterial component failure in a prosthesis or implant can result in the need for further surgical intervention or be directly life-threatening. The same is valid to industrial accidents or car crashes, when people working with devices made of steel components are at risk. It can be done in the manufacturing process or before the application of biomaterial and it's interaction with the human body. The evaluation gives a possibility for improvement of testing procedures and methods. Knowledge of inhomogeneity formation process is crucial for selecting appropriate detection procedure. It also allows to understand the formation mechanism of inhomogeneities, which must be in future avoided, [1,2,3,4].

The modeling of austenitic steels and NDE procedures are faster and more accurate, in way to achieve signal data of investigated material's objects, corresponding with testing probe signal response. With a sufficient amount of data it is possible to prepare the algorithms for signal processing and analysis, which lead to the identification of inhomogeneities. In this study, the biomaterial with presence of the stress-corrosion and fatigue cracking is evaluated. These cracks are the common ones in materials under the long-term loading, cyclic loading or when placed in extreme environment. This case corresponds to the conditions inside a human body, where these materials may be used as the artificial implants or prosthesis. The same can be stated on industry and transport, where daily use of components causes strain of constructions and extreme weather conditions (acid rain, salt, etc.) causes excessive wear of vehicles.

In our research, we use the eddy current method (ECT) for investigation of the conductive structures. This method is theoretically well known and widely utilized in practice. It is suitable for evaluating surface, subsurface and near surface defects and it is applicable for almost all materials with non-zero conductivity. Some of the current innovations of the ECT account for increasing information rate of sensed responses and include especially new excitation techniques such as pulsed, chirp and sweep-frequency. Other advances incorporate eddy current sensor arrays, flexible probes and new probes with magnetic sensors such as Hall sensors, Fluxgate magnetometers, SQUID (Superconducting Quantum Interference Device) sensors and GMR (Giant Magneto Resistance) sensors to detect small perturbation fields, [5,6,7].

The main aim of this paper is to model the cracks, which may occur in the conductive austenitic biomaterials. The finite element method software is used for this purpose. Three different material cracks are modeled, respectively. The three-dimensional models which may reflect the real case are created. The models may be helpful for better understanding of signal behaviour in electromagnetic NDE. The results are presented and discussed in this paper.

2. Linear inhomogeneity FEM model

The first biomaterial inhomogeneity model has a linear geometrical shape, which corresponds to the rectangle. It is suitable for basic investigation with modeling of various geometry and conductivity. It is the fundamental model used as a reference. This lies in fact, that the eddy current testing is the method based on comparison. The main purpose for modeling of these types of inhomogeneities, Fig. 1, is to reveal the behavior of sensed signals. Furthermore, it is possible to create the algorithms to calculate the position and properties of the biomaterial inhomogeneity.