RECENT DEVELOPMENT OF MESSINE, A 3D EDDY CURRENT MODEL

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INTRODUCTION

In the 1996 QNDE Conference, we presented a parametric forward model [1], which has been recently named MESSINE (Model for Electromagnetic Simplified Simulation In Nondestructive Evaluation), to predict eddy current signal. The proposed model first discretizes the eddy current distribution into current loops. A parametric description of the shape of these loops is given according to the observation of the results obtained with a three-dimensional finite element code which provides a realistic distribution of the induced currents. The loops' inductances and resistances are then calculated. By considering the system constituted of the coil and the current loops as a « multi-transformer », their current intensity is determined. The impedance change, which is the component of the eddy current signal, can then be deduced. The model was validated in the case of axisymmetric configurations. Comparisons with both analytical (Dodd and Deeds [2]) and numerical models showed very good agreements. Then the proposed model was applied to three-dimensional configurations. Impedance changes of a coil along rectangular through-wall slot were calculated. Comparisons with experimental results show a fairly good agreement for the impedance change phases, but a poorer one for the impedance change amplitudes. Investigations were made to improve the parametric description of the current loop deformation. One of the solutions to improve the parametric description is presented here.

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PARAMETRIC DESCRIPTION IMPROVEMENT

In the former parametric description of the current loop deformation, we did not take into account the deformation of their section: the section was supposed constant along each current loop, whereas, by the finite element code, it can be observed that the section varies along the current loops. The improvement consists of taking into account this variation.

Nearby the slot, the current loops tighten up, their section become smaller (fig. 1). Let us call $S_A$ the section of the current loop at the point A, where the current loop begins to be bent, and $S_B$ the section at the point B, where the section is the smallest.

According to the observation, from point A to point B, the current loop section decreases continuously. We tried to characterize this decrease by a linear function or by an exponential function. As we obtained some fairly good results with these two analytical functions, others were not tested. Let’s $w$ be the curvilinear coordinate along the current loop path, with point A being the coordinate system origin ($w_A = 0$). $w_B$ is the curvilinear coordinate of point B.

In the case of the linear decrease, the section from point A to point B is described by the function $S_L$:

$$S_L(w) = \left[1 + \frac{S_B}{S_A} - 1\right] \frac{w}{w_B} S_A.$$  \hfill (1)

In the case of the exponential decrease, the section from point A to point B is described by the function $S_E$:

$$S_E(w) = \exp\left(\frac{w}{w_B} \ln \frac{S_B}{S_A}\right) S_A.$$  \hfill (2)

In formulas (1) and (2), it can be seen that the section expression depends on the ratio $S_B / S_A$. By some simplifying assumptions, this ratio can be estimated.

Figure 1. Current loop section deformation
The section at a point of a current loop is inversely proportional to the current density at the same point:

$$\frac{S_B}{S_A} = \frac{J_A}{J_B} \quad (3)$$

where $J_A$ is the current density at the point A and $J_B$, the one at the point B.

Let us consider an horizontal layer of current loops of thickness $e$ and intensity $I$ (fig. 2). During the current loop deformation, the intensity $I$ is conserved. By assuming that the deformation does not modify the thickness $e$ and that the current density is uniformly distributed at the tip of the slot, $J_B$ can be expressed as:

$$J_B = \frac{I}{e \cdot c} \quad \text{with} \quad I = \sum J_{Ai} S_{Ai} \quad (4)$$

where $J_{Ai}$ and $S_{Ai}$ are the current density and section of a current loop at point $Ai$.

In definitive, according to (3) and (4), we have:

$$\frac{S_B}{S_A} = \frac{J_A \cdot e \cdot c}{\sum J_{Ai} S_{Ai}} \quad (5)$$

As the $J_{Ai}$’s are not a priori known, to estimate them, we first assumed that the current density was uniform across the layer section:

$$J_{Ai} = 1, \forall i. \quad (6)$$

With (6), the ratio $S_B / S_A$ becomes:

$$\frac{S_B}{S_A} = \frac{e \cdot c}{\sum S_{Ai}} \quad (7)$$

Using (7), the functions (1) and (2) describing the section decrease can be calculated. By describing the section variation, a more realistic parametric description of the current loops’ shape is then obtained. Other finer approximations of the ratio $S_B / S_A$ are currently investigated.

Figure 2. Deformation of a current loop layer.
RESULTS OF THE IMPROVEMENT

The new parametric description had been tested with a linear decrease and an exponential decrease of the section from point A to point B. Comparisons with experimental results were done along the slot axis, with the same plate and the same coil described in paper [1]. For each frequency, the parameters $c_1$, $c_2$ and $c_3$, defined in paper [1], are optimized with respect to the impedance changes due to a 10 mm length slot, measured experimentally at the center of the slot. The origin of the x-axis in any figures, given below, corresponds to the slot center.

The first tests on a 10 mm and a 20 mm slot at 240 kHz show that the exponential decrease gives better results than the linear one (fig. 3 and 4): at the tip of the 10 mm slot and along the 20 mm slot, the curves obtained with the exponential decrease are closer to the experimental curves than the ones obtained with the linear decrease.

Further tests were done to compare results obtained with the exponential decrease to results obtained with section being kept constant (fig. 5, 6, 7, 8, 9 and 10). These figures show results obtained with a 4mm, a 10mm and a 20 mm slot, at 240 kHz and 500 kHz. Other results are given in [3]. For any slot and any frequency, the new parametric description considerably improves the agreement between impedance change amplitudes calculated by the model and these measured experimentally.

Figure 3. Impedance change along the 10 mm slot at 240 kHz, comparison between exponential decrease section and linear decrease section.
Figure 4. Impedance change along the 20 mm slot at 240 kHz, comparison between exponential decrease section and linear decrease section.

Figure 5. Impedance change along the 10 mm slot at 240 kHz, comparison between constant section and exponential decrease section.
Figure 6. Impedance change along the 20 mm slot at 240 kHz, comparison between constant section and exponential decrease section.

Figure 7. Impedance change along the 4 mm slot at 240 kHz, comparison between constant section and exponential decrease section.
Figure 8. Impedance change along the 10 mm slot at 500 kHz, comparison between constant section and exponential decrease section.

Figure 9. Impedance change along the 20 mm slot at 500 kHz, comparison between constant section and exponential decrease section.
CONCLUSION

The first results obtained by the MESSINE eddy current parametric model [1] showed a poor agreement with experimentation results. In this paper, an improvement of the model is proposed: current loops' section variation is taking into account in the parametric description. This variation is described by an analytical function. Results obtained with the new parametric description are much closer to the experimentation results. Current investigations aim at extend the parametric description to non through-wall slot and to other positions of the coil (coil off slot axis).

REFERENCES