A REAL-TIME EDDY-CURRENT TOMOGRAPHY SYSTEM: 
DESIGN AND OPTIMIZATION

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This paper presents the design and optimization of an Eddy Current Testing system for the imaging of surface-breaking defects in conductive materials. The reconstruction of the defects is obtained by an efficient non-iterative imaging method, suitable for real time operations [1,2]. The key-point of the proposed imaging algorithm is the Monotonicity Property that holds between the object electrical resistivity and the real part, \( R(\omega) \), of the measured impedance matrix, \( Z(\omega) \), of the probe (array of coils). Indeed, in the low frequency limit (large skin-depth), \( R(\omega) \) is monotonic with respect to resistivity \( \eta \). This means that, indicating with \( V_1 \) and \( V_2 \) the domains of two possible defects (and assuming a resistivity \( \eta_I \) for the defect greater than that of the background \( \eta_{BG} \)) in the conducting domain \( V_c \), the following matrix inequality holds: \( V_1 \subseteq V_2 \subseteq V_c \Rightarrow R_1 \geq R_2 \), where \( R_1 \geq R_2 \) means that \( R_1 - R_2 \) is a positive semi-definite matrix (all its eigenvalues are non-negative).

The reconstruction strategy requires the pre-computation and storage of matrices \( R_k \) associated to a given test domain \( \Omega_k \) (a regular volume \( V_k \) with resistivity \( \eta_I \)). Let \( \delta \) be the (known) noise level affecting the experimental data cases, and \( \tilde{R}_V \) the noisy version of the resistance. Indicating with \( I \) the identity matrix, the following reconstruction are computed:

(i) \( V_U \) as the union of those \( \Omega_k \)'s such that \( R_k \geq \tilde{R}_V - \delta I \); (ii) \( V_I \) as the intersection of those \( \Omega_k \)'s such that \( R_k \leq \tilde{R}_V + \delta I \) [3, 4].

We address the problem of identifying a thin surface-breaking crack in a conductor plate (see Figure 1). The crack is assumed to be contained into a Region of Interest (ROI), which is subdivided in elementary 3D voxels. A group of contiguous voxels constitutes a test domain. The imaging method checks whether or not each test domain is completely included into the unknown defect. The following preliminary decomposition of the measured impedance will be helpful for the design: \( Z = Z_{AIR} + Z_{BG} + Z_V \), where \( Z_{AIR} \) is the impedance matrix in air (free space), \( Z_{BG} = Z - Z_{AIR} \) is the background impedance i.e. the contribution to the impedance due to the specimen (without the defect) and, finally, \( Z_V \) is the contribution due to the defect.

The first step towards the system design and optimization is to identify a “reference” probe [3].

Fig.1. The reference problem: a surface-breaking defect in a conductive specimen, with a nearby array of coils.
made of one turn quasi-filamentary coils. The reference probe must be capable of inspecting few columns of the ROI, although it must be translated to completely reconstruct a defect. The probe diameter and its radial (RT) and axial thickness (AT) were increased in order to accommodate a suitable number of windings, so to achieve resistance values of tens or hundreds of mΩ, suitable for an easy measurement with standard impedance-meters.

Given the dimensions of the target specimen and defect, radial thickness and diameters of the order of few mm were found to be suitable to this purpose [3]. For the realization of the designed testing system we focused on the case with $\phi_e=9\text{mm}$, $RT=2\text{mm}$, $AT=0.48\text{mm}$ and with wire of 0.1mm diameter. Table 1 reports the real part of the background impedance $R_{BG}$, of the air impedance $R_{AIR}$, and of the number of wire turns $N$. The noise index $\varepsilon$ is also reported, defined as the maximum tolerable noise level to correctly identify the crack. In order to verify that the signal levels associated to the defect are high enough to be measured, we carried out a parametric analysis of such levels versus the voxel size dimension. For different voxel heights and widths, Figure 1 reports the normalized defect signal level, defined as $\min \Re \left( Z_{V,i,j} \right) / R_{BG,i,j}$. Hence, using the measurements datasheet, it is possible to understand if the probe under consideration is feasible for the crack.

<table>
<thead>
<tr>
<th>$R_{BG}$ ($\Omega$)</th>
<th>$R_{AIR}$ ($\Omega$)</th>
<th>$N$</th>
<th>$\varepsilon$ (%)</th>
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<tbody>
<tr>
<td>261.12</td>
<td>4.19</td>
<td>96</td>
<td>4.01</td>
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Tab.1. Values of background resistance, air resistance, number of wire turns $N$ and noise index.

Fig.1. Normalized defect signal level for different voxel heights and for different values of voxel widths.

REFERENCES