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ELECTROMAGNETIC ADAPTIVE SENSORS ARRAY FOR NONDESTRUCTIVE TESTING OF RIVETED JOINTS

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Abstract: *Non-destructive Testing (NDT) plays an important role in the safety of high-risk components and structures, as riveted joints in bridges, structural supports, aircraft parts, even old steam engine locomotives in entertainment touristic areas, as they are subdued to high vibrations during functioning. Inspection and maintenance must be increased to ensure safety and integrity of the structures in order to extend their lifetime and for proper functioning. Corrosion damage and fatigue cracks occurring between the sheets of riveted lap joints in these structures can be undetected at first glance. The electromagnetic nondestructive evaluation based on adaptive sensors array (ASA) is simulated using FDTD software in order to design and optimize it for detection of inhomogeneities with maximum probability of detection at high reliability coefficient.*
Keywords: *adaptive sensors array, electromagnetic nondestructive evaluation, riveted joints.*

1. INTRODUCTION

Rivets are nonthreaded fasteners that are usually manufactured from steel or aluminum, consisting in a preformed head and shank, which is inserted into the material to be joined and the second head that enables the rivet to function as a fastener is formed on the free end by a variety of means known as setting. Riveted joints are often used in structural members permanently [1]. Rivets are still used in, ship body, bridges [2], tanks and shells [3], metallic aircraft structures [4], where high joint strength is required (Figure 1).

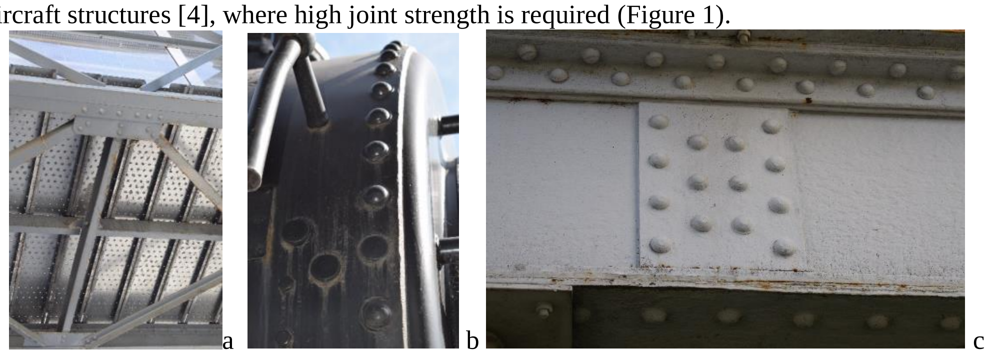

Figure 1: Riveted joins: a) bridges, b) entertainment steam engine locomotive; c) structural support

The apparition of flaws during the manufacturing process lead to low bond integrity. Most of the defects in the joints occur due to insufficient amount or uneven application of fasteners, inclusion of foreign materials, contamination, poor surface preparation. Corrosion on metal constructions is usually located around areas difficult to paint, where moisture is stored over time. This fact is specific to the areas joined by rivets. Flat surfaces are usually in better condition under a paint coating. It is known that the corrosion is accelerated by joined structures where nuts, bolts and rivets are. The rust detected around the heads can accelerate the corrosion along their stem length, causing a reduced integrity. In order to make an assessment of these structures, nondestructive testing (NDT) methods has been developed, as Magneto-optical imager (MOI) systems for inspection of damages on rivet site of layers in aircraft structures [5], ultrasound techniques [6], the pulsed eddy current testing [7], etc. The NDT method using EM sensors has been permanently developed in relation to nowadays applications. The characteristics of the sensors, the spatial resolution, the penetration depth and the conductivity of the material led to the realization of new types of sensors [8], with rotating magnetic field [9], waveguides and gratings [10], etc. The most significant challenge of ECT systems in the inspection of damages in rivet and rivet sites is that they measure the mixed signal of the rivet and damages. The regions around the rivets can be tested non-invasively by electromagnetic methods using an adaptive sensors array customized for each application. The methods involve both numerical approach and experimental investigation. This paper proposes to present the results obtained at the nondestructive testing by electromagnetic method of metallic structures jointed by rivets in order to emphasize the eventually discontinuities which favors the corrosion acceleration.

2. ADAPTIVE SENSORS ARRAY

The eddy current technique is applicable to conductive materials, it is a non-contact method, characterized by repeatability and high sensitivity to the presence of defects on and below the surface. The method is not influenced by thin material coatings, however the sensitivity is influenced by lift-off, the position of the sensor surface relative to the surface to be inspected and may be insensitive to volumetric discontinuities placed long inside the materials when the ultrasound method can be used as a complementary method [11]. Considering a conducting material containing a very thin, long sub-surface discontinuity, the magnetic field created by the emission part of eddy current sensor will be scattered by discontinuity. In order to measure the diffracted field, one can use the linear displacement of a measuring coil or of an adaptive sensor array. In this case the digitized signals from each element on the sensors are summed up, “the detection of the arrival finding” method being used [12].
The surfaces and locations of architectural assets that require non-destructive control arouse the imagination for the conceptual realization and design of new sensors. Having as a model a 2D architecture [13] the concept of the architecture was remodeled to have the ability to focus the diffracted EM field response at the time of testing.

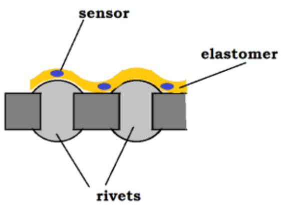

Figure 2: The concept of adaptive sensors array

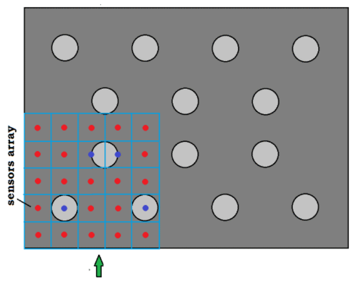

Figure 3: The design of simulation

The architecture was drawn in CAD / CAM for uploaded into simulator to analyze the details of devices. The matrix calculation required for the simulations to evaluate the amplitude and phase response of the EM sensor in the presence of rivets with and without defects is adapted to the relationships in [8]. A riveted structure (Figure 1c) has been tested to study the response of ASA. The ASA was superimposed over the designed model, Figure 3. Considering 5x5 reception coils placed over the surface to be inspected containing 14 rivets, it has been searched that the 2 rivets shall be under 2 reception coils as well as for the situation where 2 coils lay-down tangential to one rivet’s circumference.
By means of electro discharge machine, 0.2mm discontinuities with edge at depth of 0.5 and 1 mm have been machined (with less than 1% carbon, density 7.7g/cm^3) near the rivet with conductivity approx. 10^7S/m. Using ASA made on an elastomer support [13], its operation was simulated. A rectangular coil was chosen for the transmission part, with 50 turns fed by a current of 0.1A with a frequency of 25KHz. This creates inside it an electric field as uniform as possible (which was analyzed by simulation, using dyadic Green's function) [14] in which is placed the receiving part consisting of 5x5 identical coils with a distance between centers of 20mm.

3. MODELING OF ASA FUNCTIONING

The architecture is designed to be reconfigurable, the coil support being an elastomer that fits to the test surface, Figure 3, the interrogation of the receiving coils is carried up by programming the data acquisition board.
The field created by the emission coil and scattered by discontinuities is received by the array, the signal being analyzed in amplitude and phase. Simulation of array operation was performed using XFDTD software. The FDTD algorithm provides the solution for EM excitation of the frequency function sensor and is used in evaluating the approximate solutions of Maxwell's equations in differential forms[15], the working procedure was described in [13]. It is known that the field decreases exponentially inside the material and in the presence of a discontinuity it will be scattered, appearing a gradient in the Oz direction that will allow the identification of the position of the electric / magnetic field of the peaks, corresponding to the position of the discontinuities, Figure 4a. The sensor is made on elastomer support, allowing the fitting on the surface to be inspected, the coils realizing a 3D profiler. The coils that are represented higher than the other laydown on the rivets, their position being modified towards the surface of the emission coil. The surface scan was designed in a "leap-frog" style, the step being equal to the

width of the array. The amplitude of the electric and magnetic fields for the considered array placed on the surface of the conductive material in the presence of the rivets is presented in figure 4 b,c.

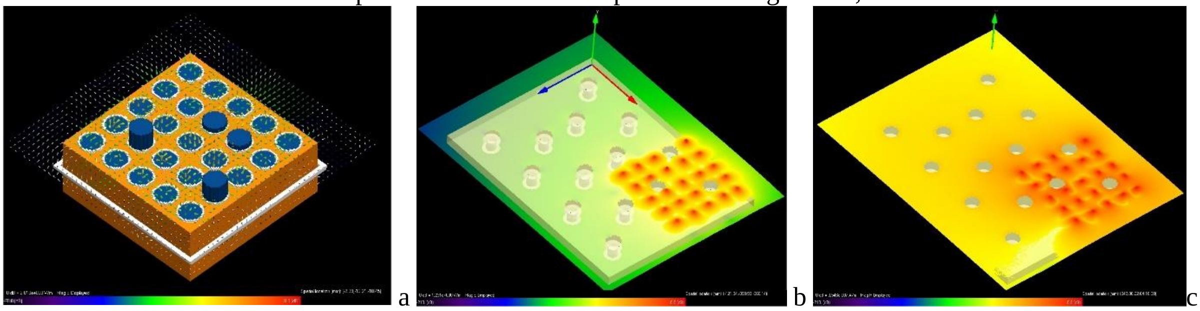

Figure 4: FDTD simulation: a) The EM field for the reception coils fitted to surface under test; b) Amplitude of electric field; c) Amplitude of magnetic field

4. EXPERIMENTAL SET-UP

The experimental set-up is presented in Figure 5. The incident magnetic field is assured by an emission coil, a rectangular frame, having 100 turns. The emission coil is fed by a function generator. The signal is amplified by Power amplifier, the reception coils are connected to a multiplexor, which significantly increases the number of sensors that can be measured by a datalogger, improving also the scanning time.

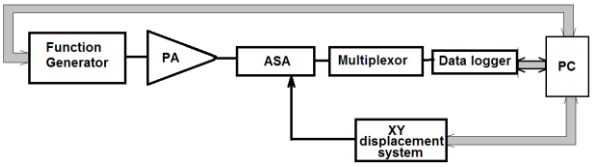

Figure 5. The experimental set-up

The output signal is amplified, the reference signal being in the same phase with the input current into the emission coil. The amplifier delivers both the amplitude and the phase of the induced electromotive force [16]. The interrogation of reception coils is correlated with the scanning steps and speed, in order to have enough time for the temporary buffer to be emptied. The displacement system, the emission system and the reception part are controlled by codes developed in Matlab. The electromagnetic image of the scanned surface has been obtained by postprocessing of the signals acquired by each coil in each scanning point, using a sub encoding reconstruction algorithm and multiple coil scheme [17]. The image reconstruction starts at the first scanning step with the set of received signals using a low number of phase-encoding gradient steps.

5. EXPERIMENTAL RESULTS

The amplitude of the field is dependent on the location of the coils in the array, Figure 6 shows the amplitude and phase of the electromotive voltage induced in the area for 25 coils placed on the surface of the conductive material with rivets, the current frequency in the emission coil being 25KHz and the amplitude 0.1A.

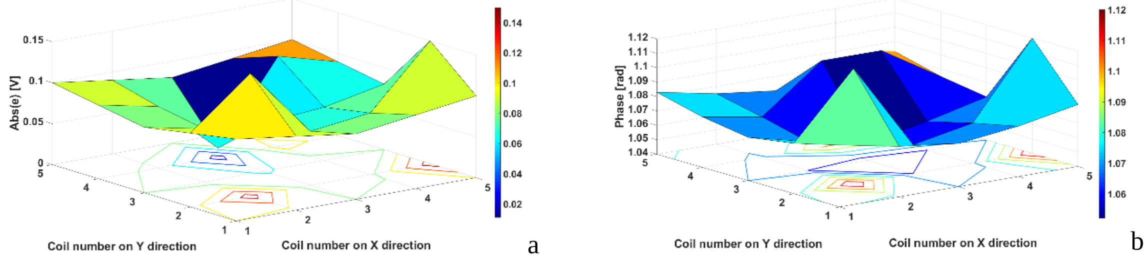

Figure 6: Amplitude and phase of the EM voltage induced in the array of 25 coils placed on the surface with rivets

The appearance and development of a crack near the rivet are specific to the fatigue or corrosion phenomena, which leads to the modification of the conductivity and implicitly of the impedance of the coils. Placing the array on a plate of the same material that has cracks near rivets with a depth of 1 mm, placed under the centers of the receiving coils (a, b) and (c, d) (the number in parentheses represents the position of the sensor in the array) get the different response signal, Figure 7.

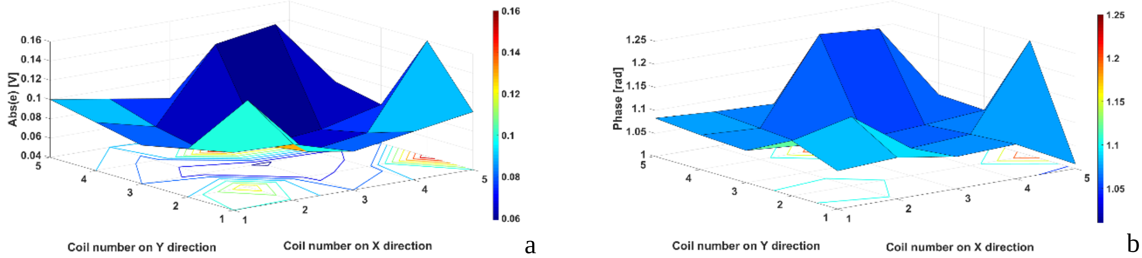

Figure 7: Amplitude and phase of the electromotive voltage induced in the array of 25 coils placed on the surface with rivets and flaws under coils (2,2) and (4,2)

The resolution of the EC sensor array can be substantially improved using the super resolution procedure [18]. Figure 8 presents the array response using the super resolution algorithm for surface with rivets without and with cracks.

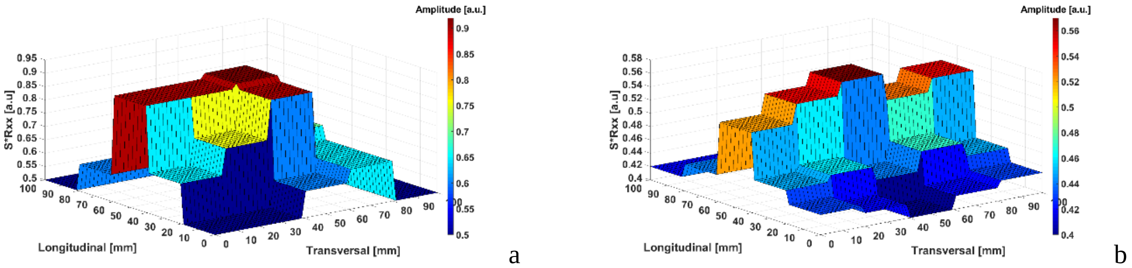

Figure 8: Localization of the fatigue cracks using the super resolution algorithm, applied to the array response.

The results obtained in the laboratory, using the described procedure, were compared with the real ones, and they show a certain degree of inaccuracy. This is especially due to the difficulty of appreciating exactly how many layers of constant conductivity there are in reality.

CONCLUSIONS

The electromagnetic nondestructive evaluation based on adaptive sensors array (ASA) has been modelled using FDTD software, with the purpose of detection of cracks in riveted metallic structure joints with maximum probability of detection at high reliability coefficient. Estimation of the location of the cracks was carried out in the present case using ASA, a super resolution algorithm was used which was applied to the response signal of the sensor matrix. The results of the application of this method suggest that the location of cracks in metallic structures with riveted joints by non-invasive methods can be applied. Further works implies the increasing the number of reception coils in order to increase the spatial resolution.

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