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ULTRASOUND ARRAY PROBE: SIGNAL PROCESSING IN CASE OF STRUCTURAL NOISE

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ABSTRACT

This work focuses on non-destructive examinations using array probe ultrasonic waves on complex materials generating a high structural noise on the examined area. During an ultrasonic examination, multiple scattering of the ultrasonic waves on the grain boundaries makes difficult the distinction between this structurally induced noise and a potential defect. The difficulty of the interpretation can moreover be increased in the near surface area because of the sub-surface wave. In order to ease the analysis of these acquisitions, some numerical processing methods are proposed. Statistical properties of the imaging results (for instance Total Focusing Method or Plane Wave Imaging) are first calculated on several sensor positions. These statistical properties are then used to post-process the imaging results and enhance any signals values that do not belong to the structural noise expected statistics. The method has been successfully tested on cast austenoferritic stainless steel coarsed-grainded mock-up, with several dB gain compared to the classical Total Focusing Method.

Keywords: ultrasound, structural noise, phased array, signal processing

NOMENCLATURE

M	number of probe elements
$\mathbf{z}$	probe position
i,j	index of probe element
T_s	sampling period
n	sampling index
$x(\mathbf{z},n,i,j)$	Full Matrix Capture at probe position $\mathbf{z}$
$I(\mathbf{z},\mathbf{w})$	imaging result at position $\mathbf{w}$

1. INTRODUCTION

Ultrasonic examinations can be strongly affected by the controlled material microstructure. Depending on the used frequency and the grain size, the grain boundaries can generate an important multiple scattering signal, also called “structural noise”. It is difficult to distinguish the numerous echo coming from the microstructure from an echo which really comes from a defect. This structural noise has the same temporal (and spectral) signature than the signal generated by the seeked defects; typical signal processing methods (filtering, wavelets …) are therefore not relevant to get rid of the structural noise.

To ease the defect detectability, strong improvement can be obtain by using array probes. A review of array probes signal processing techniques in case of structural noise can be found in [1]. Figure 1 show an example of array signals acquisition – one line of a FMC - in case of strong structural noise.

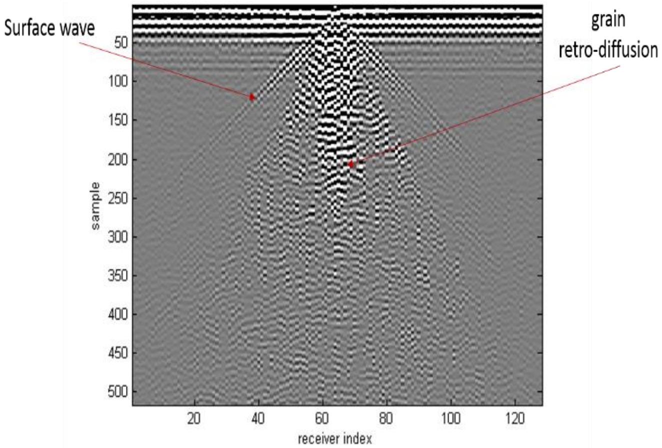

FIGURE 1: ARRAY PROBE SIGNALS IN CASE OF STRONG STRUCTURAL NOISE

A statistical processing method is proposed here. It is described in section 2. The experimental evaluation process (mock-up and sensors) is then detailed in section 3 and results are summarized in section 4.

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2. METHOD

Let $I(\boldsymbol{z}, \mathbf{w})$ be an imaging results at coordinate $\mathbf{w}$ for a given sensor position $\mathbf{z}$. $I(\boldsymbol{z}, \mathbf{w})$ can for instance be a "Total Focusing Method" (TFM) result given by:

$$I(\boldsymbol{z}, \mathbf{w}) = \left| \sum_{i=1}^{M} \sum_{j=1}^{M} x(\mathbf{z}, n(\mathbf{w}, i, j), i, j) \right|,$$

where $n(\mathbf{w}, i, j)$ is the traveling time (expressed as a number of sampling times) of a signal:

- sent by element *i*
- reflected at position **w**
- received by element *j*

A preliminary phase consists in learning the statistical structural noise influence on $I(\boldsymbol{z}, \mathbf{w})$; At position $\mathbf{w}$, the structural noise mean $A(\mathbf{w})$ and standard-deviation $B(\mathbf{w})$ can be calculated using the imaging results at N_s sensor positions:

$$A(\mathbf{w}) = \frac{1}{N_s.} \sum_{i=1}^{N_s} I(\mathbf{z_i}, \mathbf{w})$$

$$B(\mathbf{w}) = \sqrt{\frac{1}{N_s.} \sum_{i=1}^{N_s} (I(\mathbf{z_i}, \mathbf{w}) - A(\mathbf{w}))^2}$$

These statistical properties are then used to post-process the imaging results and enhance any signal values that do not belong to the structural noise expected statistics. For any imaging results $I(\boldsymbol{z}, \mathbf{w})$ we build a spatially homogenized image $I_{\text{homog}}(\boldsymbol{z}, \boldsymbol{w})$ given by:

$$I_{homog}(\mathbf{z}, \mathbf{w}) = \left| \frac{I(\mathbf{z}, \mathbf{w}) - A(\mathbf{w})}{B(\mathbf{w})} \right|$$

$I_{homog}(\mathbf{z}, \mathbf{w})$ is statistically homogeneous and can be easily used for defect detection: In undisturbed areas, it has a similar mean (0) and standard-deviation (1) at any pixel location $\mathbf{w}$.

After homogenization, some image filtering methods can be used to enhance the defect indication. We propose to use a bilateral filter [2] which enables to decrease the remaining noise variability while preserving the indications.

3. MATERIALS

FMC Acquisitions have been performed on coarse grain cast austenoferritic stainless steel. The mock-up is a parallelepipedic 98 mm-thick stainless steel block with side drilled holes of diameter 1 and 0.5 mm, at the depth of 5, 10, 20 and 30 mm.

The block has been inspected with a 128 elements phased array probe in contact mode at the central frequency of 5 MHz. The probe pitch is 0.5 mm.

4. RESULTS AND DISCUSSION

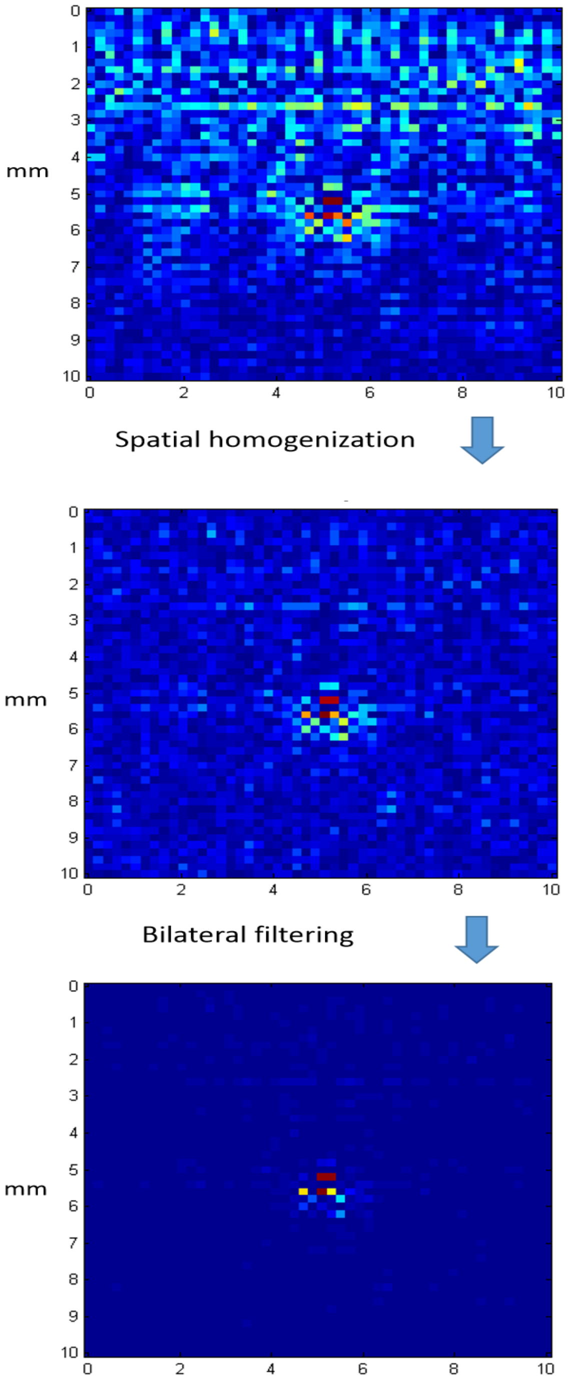

FIGURE 2: TWO-STEP PROCESSING ON A 0.5 DIAMETER SIDE DRILLED HOLE AT DEPTH 5 mm. TOP FIGURE IS THE CLASSICAL TOTAL FOCUSING METHOD RESULT.

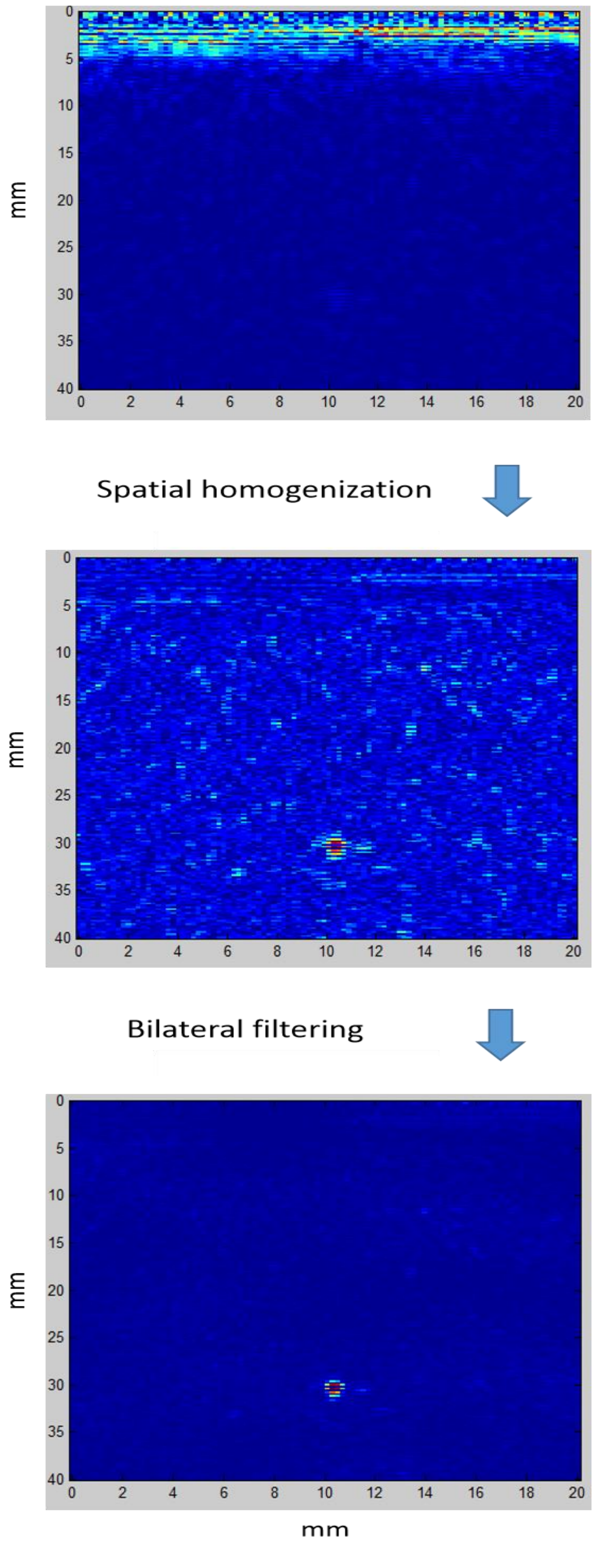

FIGURE 3: TWO-STEP PROCESSING ON A 0.5mm DIAMETER SIDE DRILLED HOLES AT DEPTH 30 mm. TOP FIGURE IS THE CLASSICAL TOTAL FOCUSING METHOD RESULT

The proposed method is illustrated on FIGURE 2 on a near-surface side drill hole (5 mm depth) and on FIGURE 3 on a 30 mm depth side drill hole.

The performances of the method is assessed by comparison with the classical Total Focusing Method reconstruction. The defect detectability is strongly enhanced, with more than 10 dB gain compared to the classical TFM.

5. CONCLUSION

A signal processing method is proposed to ease the diagnostic of component with heterogeneous micro-structure generating high structural noise. A preliminary step consists in estimating the noise influence on the imaging results statistics. These statistics are then use to homogenize the imaging results. An image filtering step is then applied to reduce the remaining noise variability while preserving the indication contrast. This method has been successfully tested on a coarse grain cast austenoferritic stainless steel mock-up where several dB have been gained compared to the classical Total Focusing Method.

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