USING APPROPRIATE MODELS AND SYNTHETIC DATA TO STUDY THE PROPERTIES OF TFM ULTRASONIC IMAGING

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Abstract

We investigate the imaging capabilities of the Total Focusing Method (TFM) by addressing side-drilled holes (SDH) as model defects. For simulating the data acquisition by an array transducer we use a 2D-Fraunhofer approximation. For the scattering of the ultrasonic waves at the SDH we use two model approaches – a Kirchhoff-type far-field approximation and the Separation of Variables method as an exact technique. On this basis we simulate time-domain ultrasonic data for various scenarios where the defect parameters SDH diameter and distance between two SDHs are varied. Addressing a commercial contact phased array probe we generate synthetic data to perform TFM imaging, also addressing the influence of noise on the image quality. We also report on further results obtained e.g. in simulating data acquisition using immersion technique, the transmission through an interface is modelled using ray theory. Investigations on the basis of synthetic data help in evaluating the performance of such imaging techniques for specific inspection situations under concern.

1. Introduction

Ultrasonic inspection techniques on the basis of phased arrays classically exploit the capabilities to focus and steer the ultrasonic beam fields. An alternative to these beam forming methods is the ‘Full-Matrix-Capture’ (FMC) approach which steps through all pairs of transmitter-receiver element combinations for data acquisition, thus recording the full data matrix. Imaging is then performed using the Total Focusing Method [1] by applying the respective delay laws to focus via algorithmic data processing. In view of defect sizing and characterization with respect to defect type, geometry and orientation such imaging techniques gain increasing relevance. The efficiency of the applied reconstruction techniques with respect to a specific inspection situation depends on the material and component parameters on the one hand as well as on the defect configuration and geometry on the other.

2. Modelling

We model an array transducer insonifying into a steel medium in contact or immersion technique. The sound in the steel medium is reflected by side-drilled holes and finally recorded by the array transducer. The number of elements is a parameter that is varied from 8 to 128. The ultrasonic field is obtained in the far-field by a 2D-Fraunhofer approximation to account for the size of each element, multiplied by the directivity
pattern of the medium (solid half-space or liquid infinite space). A tone burst at a 5 MHz central frequency is used as excitation.

In the modelling approach we make use of the scattering coefficient \( A_{\beta \rightarrow \alpha} \) of a single 2D circular scatterer of diameter \( D \). For an incident/reflected plane wave of type \( \beta/\alpha \) with velocity \( c_\beta/c_\alpha \) and unit direction vector \( e_\beta/e_\alpha \) it is under the assumptions of geometric diffraction given by [2]:

\[
A_{\beta \rightarrow \alpha} = (e_\alpha \cdot n) R_{\beta \rightarrow \alpha} \frac{D}{\sqrt{2g_{\beta \rightarrow \alpha}}} e^{ik_\alpha D g_{\beta \rightarrow \alpha}},
\]

where \( n = \frac{g_{\beta \rightarrow \alpha}}{g_{\beta \rightarrow \alpha}}, g_{\beta \rightarrow \alpha} = |g_{\beta \rightarrow \alpha}|, g_{\beta \rightarrow \alpha} = \frac{c_\alpha}{c_\beta} e_\beta - e_\alpha, \) and \( R_{\beta \rightarrow \alpha} \) is the reflection coefficient of a virtual tangential plane with normal \( n \). Multiple scattering is neglected.

3. Example result and discussion

Figure 1 exemplarily shows the TFM imaging of 8 SDHs in a steel block with a curved surface. The set-up as shown in Fig. 1a uses a 64 element array of 5 MHz insonifying via 20 mm water path. The TFM-images resulting from the synthetic data are shown in Fig. 1b and 1c, where the imaging performance can be improved by filtering out the surface-reflected signals. Geometric Theory of Diffraction was used for a computationally efficient generation of synthetic data. This is inevitable to be able to perform parametric studies on the influence on TFM imaging of several parameters describing the array transducer, the geometry of the medium to be inspected and the noise level. Comparison with an exact scattering calculation showed that the approximation and neglected contribution of the creeping wave signals do not affect the synthetic image significantly for SDHs of moderate diameters. Further work will deal with the generalization of the modelling approach to 3d.

References