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GEOMETRICAL FULL WAVEFORM INVERSION OF DEFECTS

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ABSTRACT

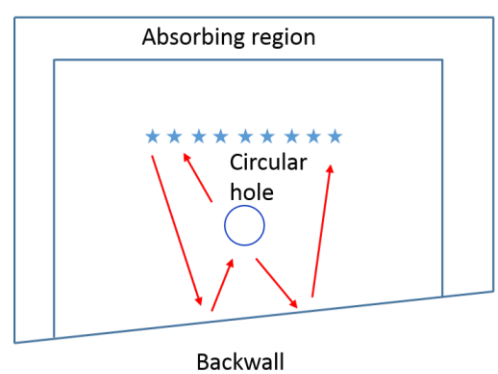
Accurate characterisation of defects provides vital information for evaluating the remaining lifetime of critical engineering components, such as those used in the nuclear industry. Ultrasonic phased array has been successfully implemented in recent years to obtain high-resolution imaging of defects, and hence to achieve improved defect characterisation [1]. Total focusing method (TFM) [1], diffraction tomography [2] and parametric manifold mapping [3] have been developed and applied for various inspection scenarios. In this study, we propose a different methodology, which utilizes the measured full waveform information to achieve an automatic defect characterisation.

The new method, which we call geometrical full waveform inversion (GFWI), is developed in the light of the concept of full waveform inversion (FWI), which originated from the geophysical community [4]. FWI starts from an initial model, which is then updated towards the real solution, provided that a suitable optimisation algorithm is applied to minimize the mismatch between the synthetic and the measurement data. The majority of FWI algorithms applied in seismic imaging aim to recover a spatial map of the material property, such as density, wavespeed, or Young's modulus. In this sense, the forward and inverse problems associated are elastic wave propagation and transmission by relatively weak scattering media. However, in Non-destructive evaluation (NDE) defects and cracks are often impenetrable, causing extremely strong scattering events. The optimisation will be trapped in local minima if using conventional FWI algorithms.

To address this problem, GFWI alternatively seeks to optimise the geometry of defects, to minimise the cost function following the FWI fashion. This procedure is based on a carefully designed formulation to calculate the deformation of the defect's boundary, following its negative geometrical boundary gradient. It turns out to be very robust to invert the shape of the defect.

In addition, characterisation of defects located near complex boundaries of engineering components is challenging. Scattered waves from defects are often masked by unwanted reflections from complex boundaries, causing artefacts to appear in images. In fact, the waves scattered between defects and the component geometry can contain vital information which can be decoded to reveal important features of defects. We will show in this study that by using GFWI, multiple scattering is automatically included in the optimisation and can help aid defect characterisation.

A simple numerical example is shown in Fig. 1. We simulate the phased array inspection of a side-drilled hole (SDH) closely located near an inclined backwall using the finite element package Pogo [5], as illustrated in Fig. 1(a). By using the GFWI algorithm, in Fig. 1(b) the rough shape of the SDH is imaged, and in Fig. 1(c) the real radius of the SDH is gradually recovered through a few iterations.



(a)

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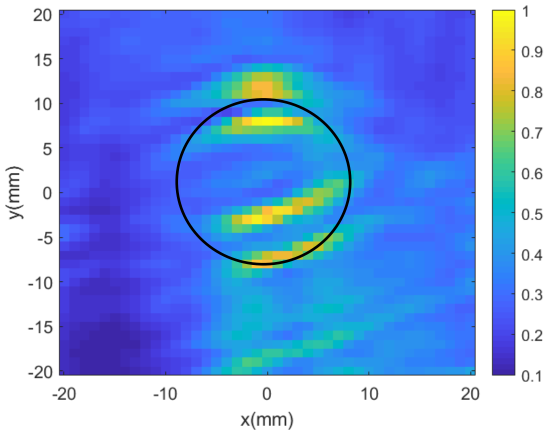
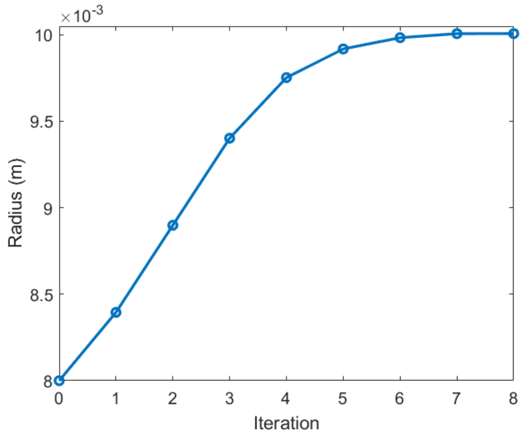


(b)



(c)

FIGURE 1: Simulation of GFWI reconstruction of a SDH (radius=10mm) near an inclined backwall (10degree). (a) Illustration of the simulation setup using a phased array. (b) Ultrasonic image of the rough shape of the SDH. Note that the backface which is not directly illuminated by the array is clearly revealed. (c) Reconstruction of the radius of the SDH through a few iterations.

Results demonstrate that GFWI successfully inverts the geometrical parameters of the defect, incorporating the multiple scattering from the backwall.

Keywords: Phased array, Full waveform inversion, Defect characterisation, Backwall, Multiple scattering

REFERENCES

[1] Drinkwater, B.W. and Wilcox, P.D., 2006, “Ultrasonic array for non-destructive evaluation: A review’’, NDT&E International, **39**, pp.525-541.

[2] Belanger, P., Cawley, P. and Simonetti, F., 2010, “Guided wave diffraction tomography within the born approximation”, IEEE UFFC, 57, pp.1405-1418.

[3] Velichko, A., Bai, L. and Drinkwater, B. W., 2017, “Ultrasonic defect characterization using parametric-manifold mapping”, Proc. Roy. Soc. London A, 473, 20170056.

[4] Pratt, R.G., Shin, C. and Hick, G. J., 1998, “Gauss–Newton and full Newton methods in frequency–space seismic waveform inversion’’, Geophys J. Int., 133, pp. 341-362.

[5] Huthwaite, P., 2014, “Accelerated finite element elastodynamic simulations using the GPU’’, J. Comp. Phys., 257, pp.687-707.