Proceedings of 46th Annual Review of Progression in Quantitative Nondestructive Evaluation
QNDE2019
July 14-19, 2019, Portland, OR, USA

QNDE2019-6965

DEFECT CHARACTERIZATION USING MULTI-VIEW TFM IMAGING ALGORITHM

Nicolas Budyn*, **Rhodri L. T. Bevan, Anthony J. Croxford, Paul D. Wilcox**
Department of Mechanical Engineering
University of Bristol
Bristol, BS8 1TR, UK

ABSTRACT

Defect characterization is an essential step of nondestructive testing which aims to determine the shape and the size of a defect once detected. The characterization of small defects remains difficult because their shape may not be resolved using imaging algorithms. This paper introduces a probabilistic characterization method based on multi-view Total Focusing Method (TFM) and an ultrasonic forward model. The measured intensities of the defect in the images act as a signature, which is compared against a database of reference defects. Using Bayesian inference, the reference defects which most credibly explain the measured signature are retrieved.

Keywords: defect characterization, ultrasonic array, ultrasonic non-destructive testing.

1 INTRODUCTION

Defect characterization is an essential step of nondestructive testing which aims to determine the shape and the size of a defect once detected. In ultrasonic testing, this can typically be achieved for larger defects by analyzing the tip diffraction and the specular reflection echoes, or in the context of ultrasonic array imaging, by directly measuring the size of the indication in an image. However, the characterization of smaller defects, where these echoes are indiscernible or the shape cannot be resolved in an image, remains difficult. Previous work for characterizing small defects has considered defects close to an array that can be probed over a range of angles to extract a portion of the scattering matrix of the defect [1, 2]. However, the geometry of many practical applications precludes this approach. In the current work, a probabilistic model for the characterization of small defects based on the multi-view total focusing method (TFM) imaging algorithm is introduced. Multi-view TFM exploits internal reflections and mode conversions of ultrasonic waves in a specimen to produce independent images [3]. The intensities of the defect in the multiple views act as a signature, which is compared against a database of reference defects generated with a model. Following previous work [2], ellipses are used as references defect to model both void/inclusions (almost circular) and crack-like defects (thin ellipse). Using Bayesian inference, the ellipses that most credibly explain the measured signature are retrieved.

2 MATERIALS AND METHODS

The inspection configuration shown in Fig. 1 approximates the inspection of the fusion face of a weld. The ultrasonic array is inclined relative to the top surface of the specimen to ensure good generation of longitudinal and transverse waves. Using multi-view TFM algorithm, 21 images of the specimen are produced to localize the defect; Fig. 1 shows as an example the rays corresponding to one of these multiple views. The core assumption of the characterization method is that the defect amplitudes in the TFM views are obtained from the data model

$$\boldsymbol{x} = \boldsymbol{m}(l, r, \varphi) + \boldsymbol{\varepsilon}, \tag{1}$$

where $\boldsymbol{x}$ is the vector of measured amplitudes in dB (one scalar per view), $\boldsymbol{m}(l, r, \varphi)$ is the vector of theoretical amplitudes in dB

*Contact author: n.budyn@bristol.ac.uk

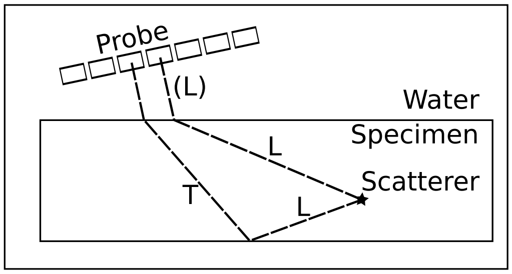

FIGURE 1. INSPECTION CONFIGURATION. THE SHOWN RAYS CORRESPOND TO THE VIEW TL–L, WHERE *L* STANDS FOR LONGITUDINAL AND *T* FOR TRANSVERSE.

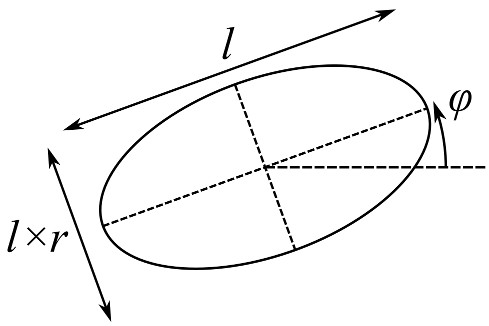

FIGURE 2. ELLIPSE PARAMETRIZATION: MAJOR LENGTH l, ASPECT RATIO r, ORIENTATION φ

for an ellipse whose parametrisation is shown in Fig. 2, and $\boldsymbol{\varepsilon}$ is a zero-centred noise vector. The theoretical amplitudes are calculated with a ray-based semi-analytical ultrasonic forward model [4, 5]. Using Bayes's theorem, the likelihood of a ellipse given a measurement is

$$f(l,r,\varphi \mid x) = \frac{f(x \mid l,r,\varphi) f(l,r,\varphi)}{\int f(x \mid l,r,\varphi) f(l,r,\varphi)\, dl\, dr\, d\varphi}, \qquad (2)$$

where $f(x \mid l,r,\varphi)$ is the likelihood associated with Eqn. (1), and $f(l,r,\varphi)$ is the prior distribution on the ellipses, which reflects prior knowledge (if any) about the defects of interest. In this study, the prior distribution is uniform for all three parameters: between 0.1 and 1.0 for the aspect ratio, between 0.1 and 4.0 mm for the major length and between $-180°$ and $180°$ (which covers all angles by symmetry) for the orientation. The most credible ellipses, i.e. the ellipses which explain the best the measurements under the data model above, are retrieved by randomly drawing from this posterior distribution.

3 RESULTS AND DISCUSSION

Three defects are considered: (a) a side-drilled hole (diameter $0.4\lambda_L$, where λ_L is the wavelength of the longitudinal wave in the specimen); (b) a rectangular notch ($1.2 \times 0.4\lambda_L$); (c) a crack (length $0.5\lambda_L$). The two first datasets were obtained experimentally; the third one with finite-element simulation with Pogo solver [6].

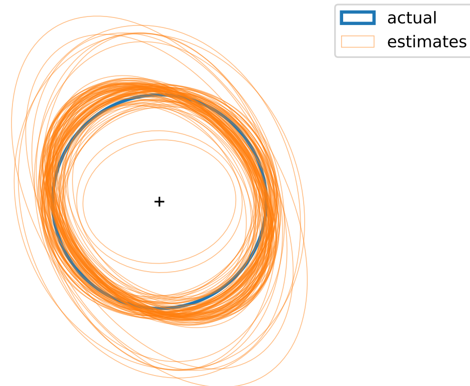

FIGURE 3. CHARACTERISATION RESULTS FOR SDH

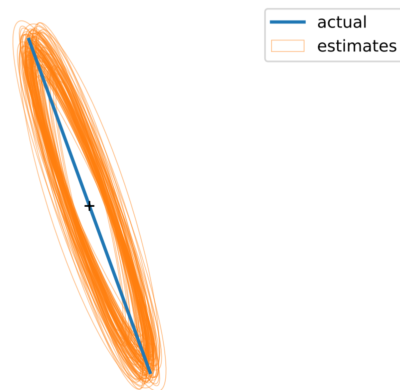

FIGURE 4. CHARACTERISATION RESULTS FOR CRACK

Figures 3, 4 and 5 show each a hundred ellipses randomly sampled from the posterior distribution in Eqn. (2). The approximate shape and orientation of the true defects are overall recovered in the three cases. The exact shape of the crack and the notch cannot be recovered because they are not ellipses; however the physical dimensions of the credible ellipses match the actual defects' ones. For the notch, this leads to a few clusters of possible solutions.

ACKNOWLEDGMENT

This work was supported by the UK Engineering and Physical Sciences Research Council (EPSRC) [grant number

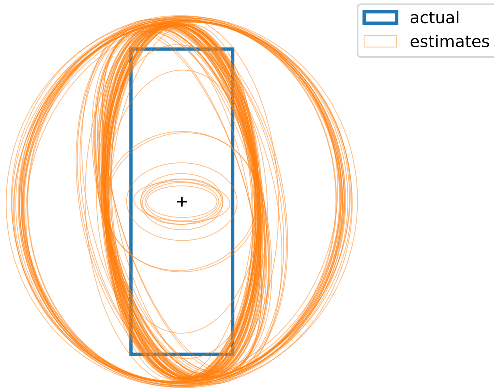

FIGURE 5. CHARACTERISATION RESULTS FOR NOTCH

EP/N015924/1]; the UK Research Centre in NDE (RCNDE); BAE Systems; EDF Energy; Hitachi; and Wood Group.

The authors thank Dr Artem Kashubin (Imperial College London) for having provided the finite-element results for the crack.

REFERENCES

[1] Bai, L., Velichko, A., and Drinkwater, B. W., 2015. "Ultrasonic characterization of crack-like defects using scattering matrix similarity metrics". *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control,* **62**(3), Mar., pp. 545–559.

[2] Bai, L., Velichko, A., and Drinkwater, B. W., 2015. "Characterization of defects using ultrasonic arrays: a dynamic classifier approach". *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control,* **62**(12), Dec., pp. 2146–2160.

[3] Zhang, J., Drinkwater, B. W., Wilcox, P. D., and Hunter, A. J., 2010. "Defect detection using ultrasonic arrays: The multi-mode total focusing method". *NDT & E International,* **43**(2), Mar., pp. 123–133.

[4] Schmerr, L. W., 2016. *Fundamentals of Ultrasonic Nondestructive Evaluation: A Modeling Approach*, 2nd ed. 2016 edition ed. Springer, New York, NY, May.

[5] Budyn, N., Bevan, R. L. T., Zhang, J., Croxford, A. J., and Wilcox, P. D. "A model for multi-view ultrasonic array inspection of small two-dimensional defects". *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control,* **accepted, in press**.

[6] Huthwaite, P., 2014. "Accelerated finite element elastodynamic simulations using the GPU". *Journal of Computational Physics,* **257**, Jan., pp. 687–707.