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# Simulation-based performances assessment of FMC-TFM array imaging techniques

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## Abstract

Advanced array imaging techniques such as FMC-TFM and derived methods have attracted a great deal of interest and are more and more used in the industry since they allow improved performances in a wide range of situations. However, questions often arise about the quantification of these performances, the relative advantages of different techniques or set-ups, and the sensitivity to uncontrolled parameters. Thus it is of interest to optimize the technique by reducing the number of ultrasonic salvos while maintaining a good level of performances. To assess the performance of array imaging techniques is not a trivial task since it requires to account for variability of influent parameters. In this communication we demonstrate the potential of simulation tool to fulfil these needs. The present study is based on the use of versatile simulation tools implemented in the CIVA platform which allow to predict results obtained when applying a given processing algorithm to a given acquisition scheme (defined by the subset of simultaneously/successively emitting/receiving elements). Comparing different processing techniques and different acquisition schemes becomes possible. Moreover, statistical analysis of results issued from meta-models derived from CIVA allow to evaluate the sensitivity of the technique to various influent parameters. Probability of detection curves can be extracted and the sizing accuracy can be quantified and compared.

## Simulation of TFM images

Advanced array imaging techniques such as FMC-TFM [1] and derived methods [2] have attracted a lot of industrial interest in recent years following the increase in computational power and hence the ability to use these methods during online non-destructive evaluation inside acquisition systems [3], [4]. As these imaging techniques become more common, their reliability assessment becomes relevant. In this paper, we propose to show how simulation can be useful for this purpose. We illustrate our approach on a representative example shown in Figure 1. Such an inspection typically results in several images corresponding to different ultrasonic propagation paths. Since current models accurately reproduce experimental images (see also Figure 1), it becomes possible to use their predictions to perform sensitivity analysis and performance demonstration.

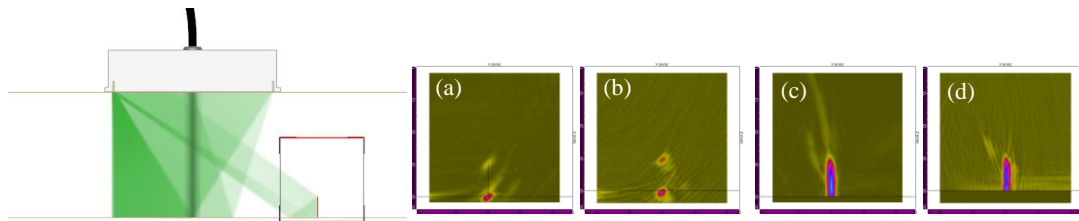


Figure 1: (left) Set-up of the phased array in FMC-TFM imaging mode. (right) Comparison of simulated and experimental imaging results for L-L (a) (b) and TT-T (c) (d) reconstruction modes.

## Sensitivity analysis

Sensitivity analysis is an efficient approach to optimize and assess the reliability of NDE techniques. In the case of the TFM images the aleatory parameters considered the effective velocity of the L and T waves in the material, as well as flaw parameters such as the depth and orientation of the flaw. Imaging algorithms and settings (such as the grid mesh) can also be taken into account. The use of numerical data base and surrogate models allow “real time” visualization of the effect of a variation in influential parameters. Sensitivity analysis can be performed on the maximum amplitude of the TFM images using Sobol analysis over the identified aleatory parameters. One typical intermediate simulation result is shown Figure 2.

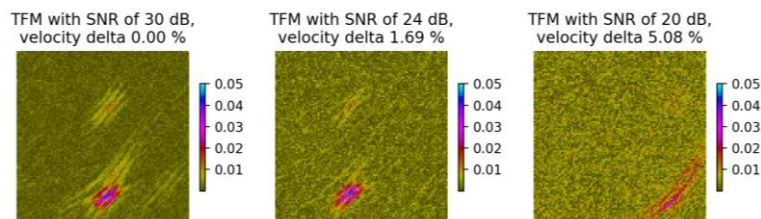


Figure 2. Simulated TFM images obtained a crack when taking into account the signal to noise ratio as well as an uncertainty on the velocity used for reconstruction of the TFM image. These images are used to compute the sensitivity analysis indicators.

## Accuracy and reliability assessment

Another aspect of the uncertainty associated to FMC-TFM image inspections is the error introduced when sizing a flaw from an image. A numerical database can be used to estimate the accuracy of the defect sizing from the image. It requires to model and automatically reproduce the sizing achieved by the operator and define a metric. Figure 3 illustrates this application on simulated diffraction echoes imaged with a FMC-TFM method. In that case, the metric we chose to use is the probability of accuracy such that  $Probability\ of\ accuracy(x) = p[\|X_{Meas} - X_{True}\| \leq x]$ , where  $X_{Meas}$  is the estimated size and  $X_{True}$  the true one.

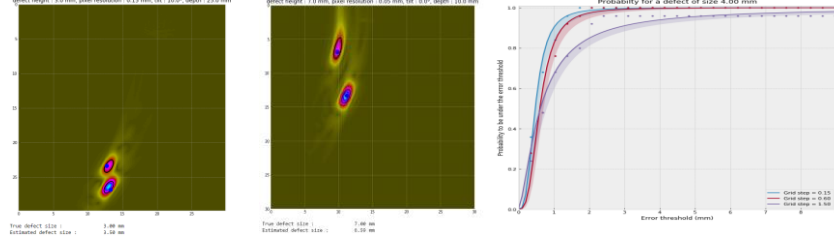


Figure 3. Illustration of the automated defect size estimation procedure: the two tip diffraction echoes of a crack are randomly placed within a -2 dB isocontour with respect to the local maximum value. This uncertainty is studied as a function of the TFM image grid size. For each grid step, a different curve is obtained by comparing the error of the estimation with a threshold.

Such an analysis complements the more usual reliability assessment, which is the estimation of the probability of detection (POD) [5] through the MAPOD approach. Figure 4 shows one example of a POD curve obtained by using a threshold defined from a calibration. The probability of false alarm can also be addressed by introducing noise in the FMC data.

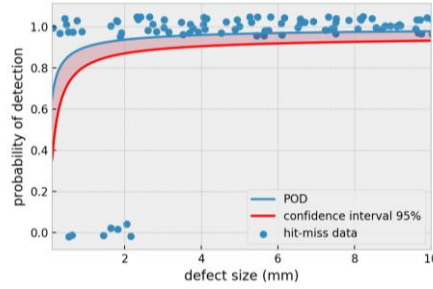


Figure 4. Simulated POD curve obtained when taking into account the uncertainty on the velocity used for reconstruction of the TFM image. The hit-miss POD is obtained by thresholding the TFM image's maximum value.

## Conclusions

The work presented in this paper deals with the ability of simulation to address uncertainty analysis in the context of TFM and derived imaging techniques. It proposes three different contributions: sensitivity analysis, sizing accuracy assessment and POD estimation on TFM images.

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