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Semi-automatic crack characterisation

L. Fradkin
Sound Mathematics Ltd.

ABSTRACT

A combination of signal processing, image processing and AI (Augmented Intelligence in the form of an expert system) has been developed for semi-automatic flaw characterisation. The resulting AutoNDE code incorporates a novel flaw characterisation algorithm, a model-based variant of TFM (Total Focusing Method), which takes into account undulations in inspection surface and backwall. It has been shown to process in real time (approx. 10 sec per crack) RF data collected in immersion and be capable of detecting and characterising with reasonable accuracy large planar defects.

OBJECTIVES

We have addressed a high level, long-term challenge of the automation of flaw characterisation and interpretation that would lead to cost effective semi-automatic NDE (Non-Destructive Evaluation) solution with high reliability. No existing instrumentation or software offers real-time semi-automatic flaw diagnostics and at present, while some phased array ultrasonic inspections themselves are automated the data collected are still being interpreted entirely by human inspectors, leading to loss of efficiency and variability in reporting [1]. The most surprising outcome of the above study conducted by TWI (The Welding Institute) is that inspectors experience the greatest difficulty when characterising large planar cracks. Probably less surprisingly the most difficult cracks to identify are those normal to inspection surface.

Approaches pursued by those who work towards automating crack characterisation can be broadly divided into pure signal processing procedures (CS - Compressed Sensing or FMC - the Full Matrix Capture) and more general but also more time-consuming model-based data processing algorithms, while human inspectors rely mostly on TOFD (Time of Flight Diffraction) technique. Our code is the first attempt to automate their thought processes using a combination of signal processing, image processing and AI.

Methods

History and issues surrounding real-time ultrasonic array imaging using FMC and TFM have been described in many publications [2] – [5]. The methods have been used for creating images of the inspected specimens, and it is only in our previous study [6] that an investigation began into their suitability for semi-automatic crack characterisation. In that study the RF (radio-frequency) data were collected by DPS (Doosan Power Systems) with a Diagnostic Sonar demonstrator, which was specifically designed for the purpose and multiplexed to a 128 element IMASONIC linear transducer array. The specimen probed was a steel block, 30 mm thick, 200 mm wide and 350 mm long, with one surface left flat and another one notched with four surface-breaking notches, four more notches were embedded underneath this notched surface. Half the notches were tilted and another half, non-tilted. The full description of the notches is given in the first column of table 1. The experiments have been performed in immersion, with the water temperature of 22.0^0 C and water path standoff distance of about 13 mm, see figure 1.

Methods (ctd)

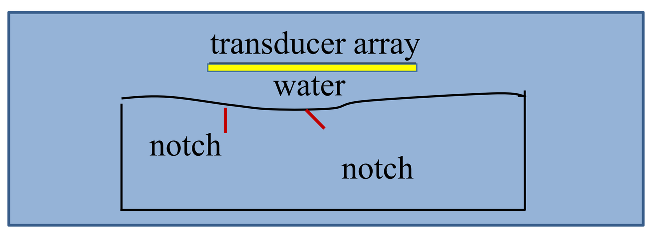

Figure 1. Schematic of the experiment.

The IMASONIC linear transducer array consists of 128 elements, with the elementary pitch of 0.8 mm, inter element space of 0.25 mm and total active length of 102.15 mm. The centre frequency of the generated signal (see figure 3) is 2 MHz 10%, the bandwidth 55 % and pulse duration < 1500 ns.

The DPS data has been used as a training set to develop a composite signal/image processing algorithm with elements of AI for semi-automatic crack characterisation. Data provided by AMEC, CEA, Westinghouse and EDF have been for testing this code.

RESULTS

The results obtained with AutoNDE using the DPS training set and various decision parameters chosen on the basis of trial and error are summarised in Table 1, a typical crack image is presented in figure 2 and the corresponding automated inspection report below this figure.

Table 1. Estimated and experimental crack parameters in the DPS training set.

Inspection surface/ crack position/ crack distance from edge	Report quality	Crack parameters		
		Extent, in mm Est/Exp	Orientation, in degrees Est/Exp	Depth, in mm Est/Exp
Flatside/Buried/24mm	90%	9/10	110/110	6/5
Flatside/Buried/62mm	70%	7/5	110/110	3/5
Flatside/Buried/113mm	30% 30%	10/10 13/10	90/90 70/90	4/5 1/5
Flatside/Buried/149mm	70%	4/5	90/90	5/5
Flatside/Breaking/25mm	70%	4/5	60/90	0/0
Flatside/Breaking/64mm	80%	9/10	75/90	0/0
Flatside/Breaking/113mm	80%	4/5	80/110	0/0
Flatside/Breaking/150mm	70%	10/10	100/110	0/0
Notchside/Buried/24mm	50%	9/10	115/110	8/5
Notchside/Buried/62mm	90%	7/5	110/110	7/5
Notchside/Buried/113mm	80%	12/10	95/90	4/5
Notchside/Buried/149mm	40%	5/5	85/90	5/5
Notchside/Breaking/25mm	50%	5/5	105/90	2/0
Notchside/Breaking/70mm	60%	9/10	85/90	2/0
Notchside/Breaking/113mm	80%	6/5	105/110	2/0
Notchside/Breaking/155mm	60%	9/10	110/110	4/0

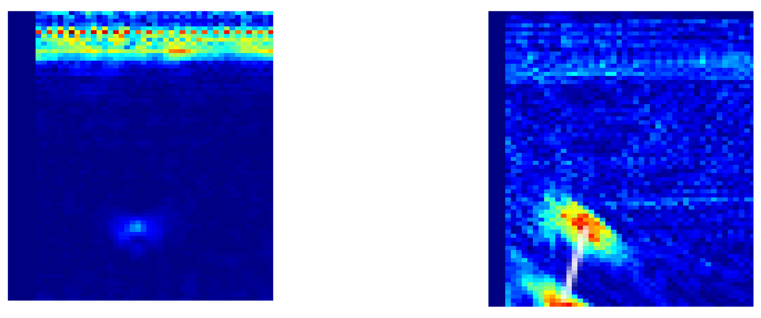

Figure 2. Training DPS data set: typical TFM and MTFM images of the buried notch

POSSIBLE INSPECTION REPORT

File: ../Data/DoosanFlatsideBreaking64mm

GROUP - 6:

A possible planar defect is detected.
Defect depth = 0 mm
Defect extent = 9 mm
Defect orientation = 75 deg

Report Quality = 60%

When tested on the CEA data a reliable CIVA TFM image of a backwall crack could be obtained only by using a mixed mode inspection, see figure 3 a). Using the same mode, AutoNDE produced a similar, see figure 3 b).

Results (ctd)

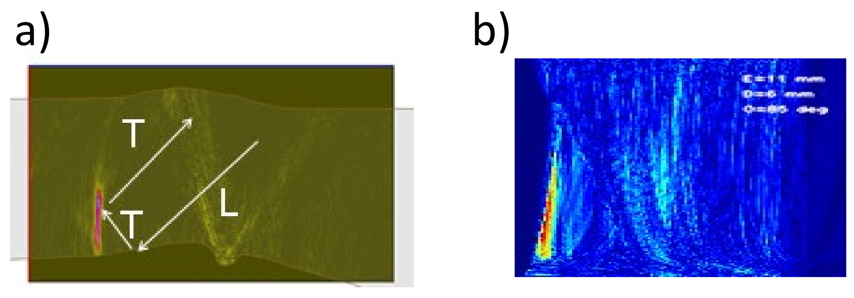

Figure 3. The back wall crack imaged (using the half-skip LTT mode) with a) CIVA and b) the AutoNDE code.

CONCLUSIONS

A novel modification of TFM procedure has been developed and implemented in C for semi-automated characterisation of large planar cracks in stainless steel, smooth or rough. Even when it is possible to simulate specular reflection, simulating TOFD seems to give more reliable sizing. It is possible to extent the procedure to other types of cracks and geometrical configurations, developing a comprehensive library of generic models for deployment in a portable probe capable of acting as a real-time assistant to an ultrasonic inspector and interpreter. More effort is required to make automation faster and more robust. The proposed solution for semi-automatic characterisation of safety critical defects and presenting clear and unambiguous reports would support both existing and new fleet of nuclear reactors.

The current version of AutoNDE is being developed under the auspices of the Chimera project carried out in collaboration with Forth, Headlights, RACE, Roll-Royce and TWI within the Innovate UK framework of Robotics and AI in Challenging Environments. It lays the foundation for the automation of assessing vessel fitness for service and will be integrated into the Chimera robotic system. However, it can also be easily developed into a stand alone application. The future work on weld crack detection and characterisation will expand the scope of the software.

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The Main Contact

Larissa Fradkin
l.fradkin@soundmathematics.com