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ENHANCED CHARACTERISATION OF BRANCHED SURFACE BREAKING CRACKS USING MULTI-MODE REVERSE TIME MIGRATION (MMRTM) METHOD

Abhishek Saini, Zheng Fan[1]
School of Mechanical and Aerospace Engineering,
Nanyang Technological University, 50 Nanyang
Avenue, Singapore 637798, Singapore

Jinwei Fang
China University of Petroleum, 102249
Changping, Beijing, China

ABSTRACT

Characterisation of the branched surface breaking cracks is one of the challenges in ultrasonic Non-Destructive Evaluation (NDE) applications that may cause underestimation and misdetection. In this paper, an advanced ultrasonic imaging methodology, termed as the Multi-Mode Reverse-Time Migration (MMRTM) imaging algorithm is proposed in which any combination of wavefield modes can be used to produce an image of the complicated defects. This approach is implemented by post-processing the full matrix capture (FMC) of array data to achieve enhanced defect detection and characterization. An elastic finite difference (FD) model is used to predict the ultrasonic FMC data and demonstrate the performance of the MMRTM concept. The MMRTM of ultrasonic data requires separating longitudinal (P) and shear (S) reflections before, applying the imaging condition. The Vector-based FD model allows the decomposition of the elastic source and receiver wavefields into P and S wave vectors by decoupled elastodynamic extrapolation. Finally, the PP and PS images of branched surface breaking cracks are presented from the numerical data. MMRTM is determined as a potential technique for the evaluation of various complex defects such as fatigue cracks and stress corrosion cracks.

Keywords: Complex surface breaking cracks, elastic wavefield imaging, MMRTM

1. INTRODUCTION

Quantitative analysis of crack like defects has become an important target in nondestructive evaluation (NDE) [1]. Surface breaking cracks (SBCs) are one of the types of cracks which initiate from the surface of the structure and propagate in irregular direction. SBCs resulting from fatigue and harsh operating conditions are commonly found in engineering structures such as rail tracks, aircraft structure, gears, bearings, pressure vessels and pipelines [2-7]. Accurate characterisation of SBCs leads to more quantitative monitoring of structures being inspected, providing essential information to maintain the integrity of critical engineering structures.

A popular sub-surface wave-based imaging method exists in the field of geophysics and it is found to be a potential technique for imaging complex SBCs, which is called the Reverse Time Migration (RTM) [8]. The physics of RTM is based on the principle of time reversal of waves [9, 10]. The images of the structures are created from the FMC data by constructing the source elastic wavefields propagating forward in time and reconstructs the receiver elastic wavefields propagating backwards in time.

In this paper, a modification of RTM imaging algorithm is proposed to use both scattered longitudinal (L) and mode-converted shear waves (T) in ultrasonic phased array imaging, which is called the multi-mode reverse time migration (MMRTM). The MMRTM can use any combination of wavefield modes to produce an image of complicated defects such as PP, PS, SS, and SP images. The MMRTM of ultrasonic data requires separating P and S reflections before, applying the imaging condition. The vector-based (VB) finite difference model allows the decomposition of the elastic source and receiver wavefields into P and S wave vectors by decoupled elastodynamic extrapolation [11, 12]. Decomposed P and S vector wavefields are than used to generate the MMRTM images by zero-lag cross-correlated imaging condition.

The vector-based MMRTM can improve the imaging of branched SBCs by eliminating the crosstalk between the converted modes. It also enhances the illumination in areas in which the L-wave signals are weak.

2. METHODOLOGY

Figure 1 contains the flowchart of elastic MMRTM with the VB imaging condition. The source wavefield extrapolation was done from the FMC data before the receiver wavefield extrapolation followed by P and S decomposition [13]. The decomposed P and S wavefields were than used for the imaging

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[1] Contact author: ZFAN@ntu.edu.sg

condition. The first order stress-velocity elastodynamic equations were used in the FD model for wavefield extrapolation [11, 14].

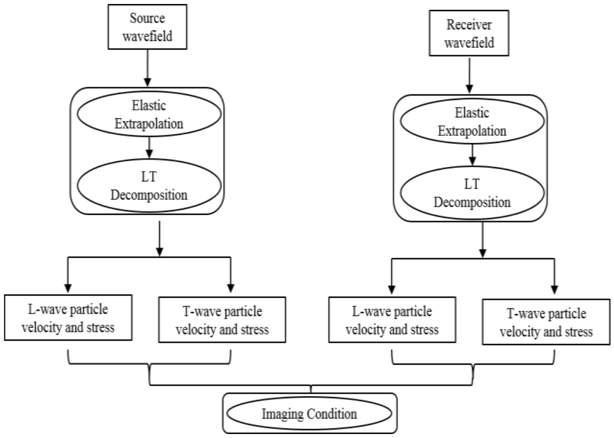

FIGURE 1: FLOWCHART OF ELASTIC MMRTM WITH VECTOR-BASED IMAGING CONDITION.

2.1 MMRTM IMAGING CONDITION

P and S decomposition is an important step to get multimode images. The decomposition of the wavefields was performed in the vector domain, so the vector information in the input elastic wavefield is preserved in the output [12]. The imaging condition can be obtained by the VB cross-correlation imaging condition and is given by the following equations.

$$I_{pp} = \int_T v_{x_{src}}^{p} v_{x_{rec}}^{p} + v_{z_{src}}^{p} v_{z_{rec}}^{p}\, dt \tag{1}$$

$$I_{ss} = \int_T v_{x_{src}}^{s} v_{x_{rec}}^{s} + v_{z_{src}}^{s} v_{z_{rec}}^{s}\, dt \tag{2}$$

$$I_{ps} = \int_T v_{x_{src}}^{p} v_{x_{rec}}^{s} + v_{z_{src}}^{p} v_{z_{rec}}^{s}\, dt \tag{3}$$

$$I_{sP} = \int_T v_{x_{src}}^{s} v_{x_{rec}}^{p} + v_{z_{src}}^{s} v_{z_{rec}}^{p}\, dt, \tag{4}$$

where p and s mark the separated wavefield related to P-wave and S-wave; src and rec are the wavefield from the source and receiver wavefield extrapolations respectively.

By using the above imaging conditions, the decoupled wavefield condition can be obtained at each time step.

3. NUMERICAL SIMULATIONS

In this paper, a finite difference time domain (FDTD) simulation technique is used to implement MMRTM algorithm. The fifth-order in space, second-order in time, staggered-grid finite-difference solution of the isotropic stress particle-velocity elastodynamic equations were implemented in the simulations. The absorbing boundary was applied to get the scattered wavefield from the SBC. The VB imaging condition was tested for the complex-shaped crack; the schematic of sample geometry with complex-shape crack and phased array probe is shown in figure 2. A linear phased array of pitch 1.5 mm was used in the numerical simulation to generate FMC data. Elements are assumed to be large in the y-direction, which propagate the ultrasound in x-z plane for the two-dimensional simulation model. The input signal for the simulation model was a two-cycle Hann windowed tone burst signal with a centre frequency of 2 MHz. The material properties of the sample is presented in Table 1

TABLE 1: MATERIAL PROPERTIES AND SOUND VELOCITY FOR THE SIMULATION MODEL.

	Young's modulus E (GPa)	Poisson's ratio μ	Longitudinal velocity, V_L (ms^{-1})	Shear velocity, V_S (ms^{-1})
Aluminum	72.32	0.33	6297.97	3173.33

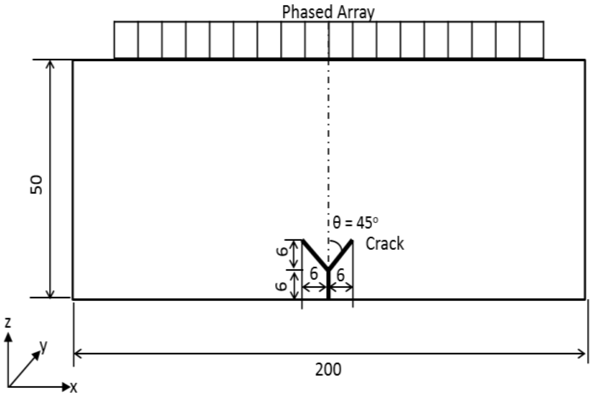

FIGURE 2: SCHEMATIC DIAGRAM SHOWING THE SAMPLE GEOMETRY WITH COMPLEX-SHAPE CRACK AND PHASED ARRAY PROBE.

4. RESULTS AND DISCUSSION

Figure 3 and 4 show the PP-RTM and PS-RTM images respectively obtained from the simulated data by using the P and S vector decomposition algorithm and the VB imaging condition. It can be seen that the VB image condition for elastic MMRTM can image the V-shape crack clearly which can be sized directly from the image. It should be noted that the VB elastic MMRTM can be further implemented for more complex branched shape SBCs for better defect assessment of critical engineering structures.

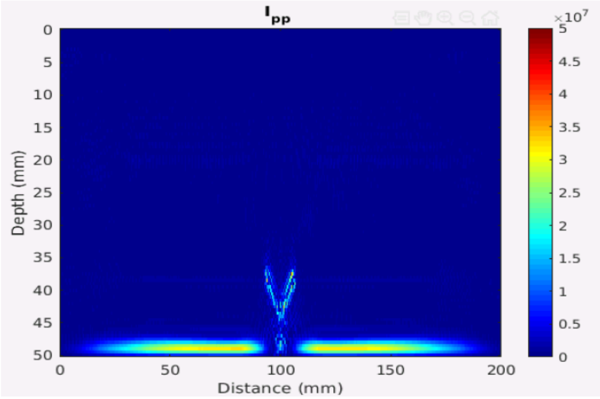

FIGURE 3: MMRTM IMAGE FROM THE SIMULATED SCATTERED DATA USING PP MODE.

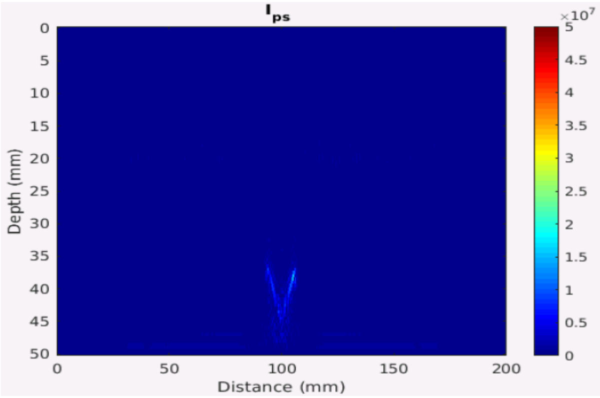

FIGURE 4: MMRTM IMAGE FROM THE SIMULATED SCATTERED DATA USING PS MODE.

5. CONCLUSION

A new workflow called vector-based elastic multimode recverse time migration is implemented to image branched surface breaking cracks. The multimode reverse time migration is found to be a potential technique for the characterisation of complex branched shape surface breaking cracks. The MMRTM can provide more detailed defect image and structural information using different combinations of ultrasonic wave modes. Numerical tests show acceptable results for the migrated images.

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