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ULTRASONIC FLAW RECOGNITION BY MULTI-ANGLE PHASED ARRAY DATA INTEGRATION

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ABSTRACT

This study presents a method of ultrasonic flaw identification using phased-array data. Raw data of each individual channel of the phased array are stored in a two-dimensional matrix. The data trimming and de-noising are used to exclude data out of the boundary of the inspection object and remove the speckle type of noise components from the raw data. The resulting data are passed into a sequence of signal processing operations to identify embedded flaws. A shape-based filtering is used to reduce the intensity of geometric noise components due to the non-uniform microstructures introduced in the manufacturing process. Two such filters are applied to remove the horizontal and vertical noise bands, and the two resulting data matrices are combined to determine the intensity matrix of the potential flaw regions. A connected component analysis is employed to form pixel groups of the potential flaws. A dimensional thresholding is used to remove unrealistic potential flaws. The overall method is demonstrated and validated using realistic phased array experimental data.

Keywords: flaw recognition, phased array, ultrasonic

1. INTRODUCTION

Ultrasonic bulk waves have excellent propagation properties for metal materials, and its interaction with material discontinuities has been utilized as an efficient tool for damage detection since 40s [1]. An ultrasonic transducer can emit high frequency bulk waves and simultaneously acquire the reflected echoes from the surface of the materials. The amplitude of the reflected echoes and the time of its occurrence are used to interrogate the internal states of the materials. In particular, this pulse-echo configuration is suitable for in-situ, intermediate, and overhaul maintenance via manual and automated procedures [2], and has become one of the most widely-used configurations for product inspection, structural health monitoring, and safety assurance [3]. A phased array transducer has a group of individually controllable actuators, allowing for electronically steering the beam direction and adjusting the depth of the focus [4]. Using phased array bulk waves has several advantages over the conventional monolithic bulk waves. For example, it can sweep a sectorial domain at one time, and by moving the probe the same internal location can be interrogated from multiple directions and locations [5]. Consequently, the reliability of damage detections can greatly be improved. In addition, the efficiency and flexibility of phased array also allows for rapid inspections of material blocks, reducing the overall inspection time. The ultrasonic data acquired by a conventional monolithic transducer at a specific location are usually presented in a two-dimensional plot, representing the echo amplitude vs. time-of-flight [6]. Manual interpretations of such data are not difficult due to the simplicity of such plots. However, phased array transducers emit and acquire the data simultaneously from multiple angles of incidence, making the manual interpretation difficult.

Recent studies on flaw detection with ultrasonic phased array have been focused on improving the imaging technology using various signal processing techniques. Camacho et al. [7] developed an ultrasound approach based on Total Focusing Method (TFM) and Phase Coherence Imaging (PCI) to monitor crack size during fatigue test. Li et al. [8] reported an improved TFM imaging technique by combining velocity anisotropy and optimizing the aperture angle and frequency filter to improve the quality of the resulting images. Meksen et al. [9] proposed a method based on sparse matrix representation instead of the whole data in Time-Of-Flight Diffraction (TOFD) technique to improve the efficiency in dealing with large datasets. Sinclair et al. [10] developed a digital signal processing scheme based on the synthetic aperture focusing technique (SAFT). By combining with a variation of Wiener filtering and autoregressive spectral extrapolation, the image resolution and size quantification were improved in weld applications. Fan et al. [11] developed an ultrasonic imaging method for concrete filled steel tube inspections using time-of-flight data interpolation and

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normalization. Brizuela et al. [12] reported an ultrasonic imaging method for phased array data with dynamic depth focusing, SAFT and PCI to improve the image resolution. Zhang et al. [13] proposed a method for sizing crack-like defects with similar or less size than the wavelength by measuring the scattering coefficient matrix of defects. Prager et al. [14] compared two defect sizing techniques, SAFT and TOFD, on a reactor pressure vessel mock-up. The detection and sizing capabilities of SAFT were observed to be better than that of TOFD, but SAFT has a higher computational demand. Peng et al. [15] presented an ultrasonic image-based sizing technique which can measure the cracks larger than two wavelengths. Although many efforts have been made towards improving the image quality and resolution, most of the reported methods deal with static images or data acquired at one location. For industrial applications where automated and continuous data acquisition are mandatory, data fusion and flaw detection becomes extremely nontrivial when the same spot is interrogated from different angles of incidence at different locations [5]. Furthermore, few studies have been reported on rapid and reliable identification and quantification of flaws incorporating multi-channel phased array data. Therefore, a systematical method for reliable recognition of embedded flaws using phased array data is highly demanded, yet still remains a great challenge.

The objective of this study is to develop a systematical methodology for embedded flaw identification using phased array ultrasonic data. The rest of the paper is organized as the follows. The proposed method is presented in details where all the necessary data processing steps are discussed in details. After that the proposed method is demonstrated using experimental data acquired from a block object with artificial flaws. Following that an aluminum alloy with natural flaws are used to validate the method. Finally conclusions are drawn.

2. METHODOLOGY DEVELOPMENT

The overall methodology is illustrated in FIGURE 1. First, raw phased array data acquired from the objected being inspected are stored as matrices. The data of each channels are stored as a two-dimensional intensity matrix. The matrix is first trimmed according to the sound speed and the physical boundary of the object. Data out of the range are removed. The remainder of the data are filtered using a de-noise filter, e.g., a Gaussian filter, to eliminate the speckle noise components. The resulting data are passed into the flaw identification procedure where a sequence signal processing steps are applied. Two shape-based filters are used to remove horizontal and vertical geometric noise components, respectively. The two resulting filtered data are combined in the channel integration step to form the intensity image of potential flaw regions. The connected component analysis is subsequently employed to obtain the pixel groups of each of the flaw regions. A final dimensional thresholding is used to exclude unrealistic flaw regions and the remaining flaw regions are the identified flaws.

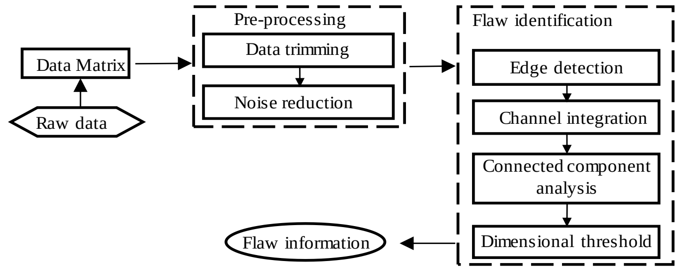

FIGURE 1: THE FLOWCHART OF THE PROPOSED METHOD

3. EXPERIMENTAL VALIDATIONS

Phased array ultrasonic testing is performed to acquire data from a 4340 steel block with six artificial side-drilled holes (SDHs). The data are used to demonstrate the overall procedure and validate the effectiveness of the proposed method. The dimension of the block and the locations of features are shown in FIGURE 2. The length and height of the block are 285.00 mm and 76.10 mm respectively. The diameter of all SDHs is 1.27mm. The distance from the first SDH to the top surface is 38.10mm and to the side surface is 16.70mm. The horizontal and vertical distance for two adjacent SDHs are 50.80 mm and 7.62 mm. A 5MHz liner phased array probe with a position encoder is used for collecting data. In the testing, the probe is attached onto the scanning surface using liquid couplants directly and it is configured to sweep over angles from -20 ° to +20 ° with a step size of 1 °. It is defined that the angle of incidence of the beam, which is perpendicular to the scanning surface, is 0 °. The probe is moved on the top surface of the block along the direction perpendicular to the axis of SDHs, and the step length along the scan path is 0.1mm. The sampling time interval is 10-8 s and the sound propagation speed in the 4340 steel is 5920m/s. Then the acquired data can be processed and analyzed using our method.

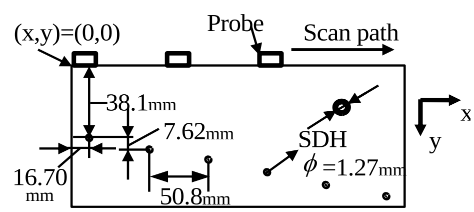

FIGURE 2: A 4340 STEEL BLOCK WITH SIX SDHS

The results of each intermediate stages of our proposed method are shown in FIGURE.3. In FIGURE 3 (A) and (B), the phased array data captured by the beam with 0 degree and 10 degree incident angles at different locations on one cross section are represented by a color look-up table respectively. It can be found that the data are corrupted with various noises. For example, the interface noise caused by the contacting surface are exist at the beginning of images, and the speckle noise, electrical noise and the geometric echo noise also contaminate the images. FIGURE 3 (C) and (D) present the flaw identification results for the raw data in FIGURE 3 (A) and (B) correspondingly. The noise are elimilated effectively, and the internal damage in the block (i.e. six SDHs) are visualized clearly.

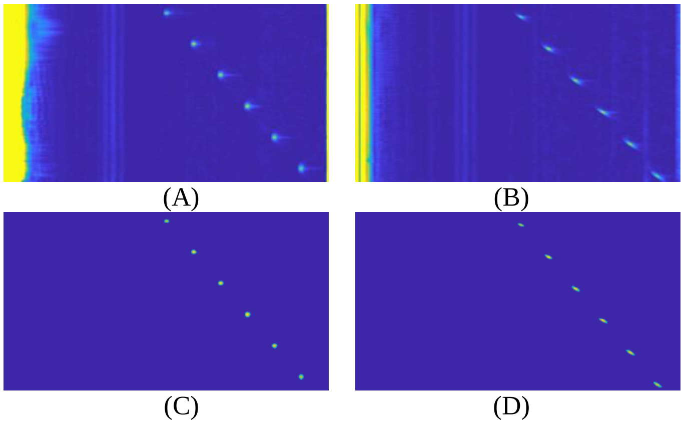

FIGURE 3: (A) (B) PHASED ARRAY DATA CAPTURED BY THE BEAM WITH 0 DEGREE AND 10 DEGREE INCIDENT ANGLES AT DIFFERENT LOCATION RESPECTIVELY, (C) (D) FLAW RECOGNITION RESULT FOR THE RAW DATA IN (A) AND (B) CORRESPONDINGLY.

4. CONCLUSION

This study presents a systematical method for ultrasonic flaw identification using phased array data. The method consists of data trimming and de-noising, shape-based filtering, connected component analysis, and dimensional thresholding. The overall procedure is demonstrated using realistic experimental data acquired on metal blocks with artificial flaws. It is further validated using aluminum blocks with natural flaws. Based on the current experimental data, the following conclusions can be drawn. (1) The proposed method can greatly eliminate speckle and background noise components, and (2) the proposed shape-based filters, implemented as convolution operations, can efficiently reduce the geometric noise components in horizontal and vertical directions.

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