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Reliability assessment for laser-induced phased array ultrasound detection

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1. Introduction

Laser-induced phased array (LIPA) technique has been researched for over 10 years as a completely non-contact inspection method for both transmitting and receiving from the target. In this method, a single excitation laser and a vibrometer are used to generate virtual array elements as various points. Defects are then detected by applying the TFM (Total Focusing Method) imaging technique which breaks through the low S/N ratio with full matrix capture data.[1,2] Even though full matrix capture is available, S/N ratio can be different according to the position of generator and detector due to directivity of ultrasonic waves generated by a finite size source.[3] So, suitable inspection strategy is required to inspect defects using LIPA. A conventional phased array ultrasonic transducer has n elements and uses time delays applied to each element to steer and focus the beam. In contrast, the LIPA ultrasonic technique cannot steer or focus the beam because it utilizes a single generation laser and a single vibrometer.

In this study, we employed the TFM imaging technique, which creates an image by focusing on and receiving signals from every point within a region of interest (ROI). With this method, however, the data acquisition time increases exponentially with the number of array elements and the number of points in the ROI. Consequently, slow inspection speed is frequently cited as a major drawback in the application of LIPA ultrasound. Therefore, this study aims to propose a method to address this limitation by reliability assessment of LIPA system. To improve inspection speed of LIPA ultrasound, optimizing the number of elements and pulse repetition rate (PRF) should be considered. We compare the image quality of LIPA system with different number of elements and PRF with specimen of side drilled holes implemented.

2. Methods and Results

2.1 LIPA system setup

The LIPA ultrasonic system, as shown in Fig. 1, is broadly divided into two main parts: a generation unit, consisting of a laser generator and a galvanometer, and a reception unit, consisting of a vibrometer and a linear stage. In the excitation unit, the PDA10A2 measures the light from the generated laser to send a triggering signal for synchronization.

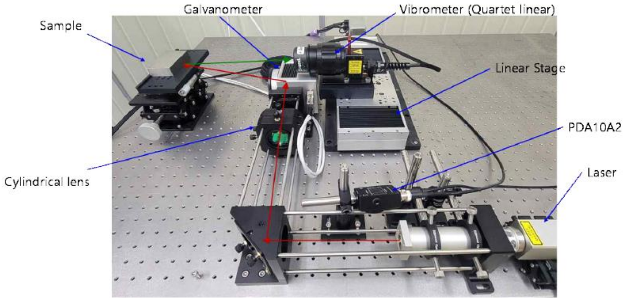

Fig. 1 Laser induced phased array ultrasonic system

When data acquisition begins, the receiving laser moves to the first scanning points, at which time the generated laser acquires signals from N points, If there are M acquisition points for the receiving laser, a total of M×N signals are acquired. Since the number of reception points M is typically the same as the number of excitation points N, a final set of N×N signals is captured.

The acquired signals can be represented in a matrix format as shown in Fig. 2, where the rows represent the transmitters (excitation unit) and the columns represent the receivers (reception unit). In other words, s_{ij} represents the signal transmitted from the i-th position and received at the j-th position. This complete data set is known as Full Matrix Capture (MFC).

The phased array ultrasonic image signal can be obtained from the measured MFC data using the TFM. The TFM signal is expressed as follows.

$$I(r) = \left|\sum_{g=1}^{n}\sum_{d=1}^{n} s_{gd}\left(t_{gd}(r)\right)\right| \qquad (1)$$

In equation (1), $d_g(r)$ represents the distance from the transmitter to a point r, and $d_d(r)$ represents the distance from the receiver to r. Therefore, the time-of-flight, t_{gd}, corresponds to the total travel path $(d_g(r) + d_d(r))$ / c_T, and s_{gd} denotes the amplitude of the A-scan signal at time t_{gd}.

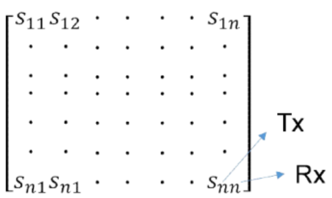

Fig. 2. Full matrix capture with obtained by laser induced phased array ultrasonic system.

The experimental specimen was prepared as shown in Fig. 3. The material is STS304 with a thickness of 25 mm. A total of eleven side-drilled holes (SDHs) with a diameter of 0.05~1.50 mm were machined into it. The LIPA measurement was conducted with a total of 64 elements, and the element pitch was set to 0.155 mm. To improve the inspection speed, TFM images acquired using 8~64 elements with different PRF were compared. All of LIPA measurements were performed over a fixed canning range of 9.765 mm by adjusting the element pitch accordingly.

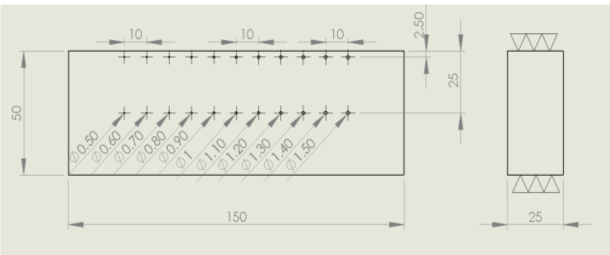

Fig. 3. Specification of test specimen.

2.2 LIPA measurement results

Fig. 4 shows the results of image using LIPA ultrasonic measurements with different PRF of 1 and 2 kHz. To improve the inspection speed, the number of elements was adjusted to 64, 34 and 18. As can be seen in Fig. 4, when the image is acquired using 18 elements, severe artifacts signal occur, making it very difficult to locate the actual defects. This suggests that at least 34 elements are required to inspect the 0.5 mm side-drilled hole. Comparing the images from 64 and 34 elements, there is no significant difference to detect the defect signal. But the time required to measure 64 elements at 1 kHz was 39 minutes and 47 seconds, conversely, for 34 elements at 2 kHz was 6 minutes and 30 seconds. In fact, other artifacts are observed in the 34 elements image but it resulted in a time saving of approximately 30 minutes. Using these test results, we could obtain the probability of detection (POD) for LIPA measurement conditions.

3. Conclusions

In this paper, we presented experimental results based on the number of elements to improve the speed of laser induced phased array ultrasonic measurements. For the case of side-drilled holes, it was found that a minimum of 34 elements is required to achieve the desired imaging results in case of 0.5 mm diameter. These findings may vary depending on the defect type and the environment. Therefore, it is necessary to identify the optimal conditions by conducting tests on a calibration specimen. It is need to POD evaluation for defect detection applications of LIPA.

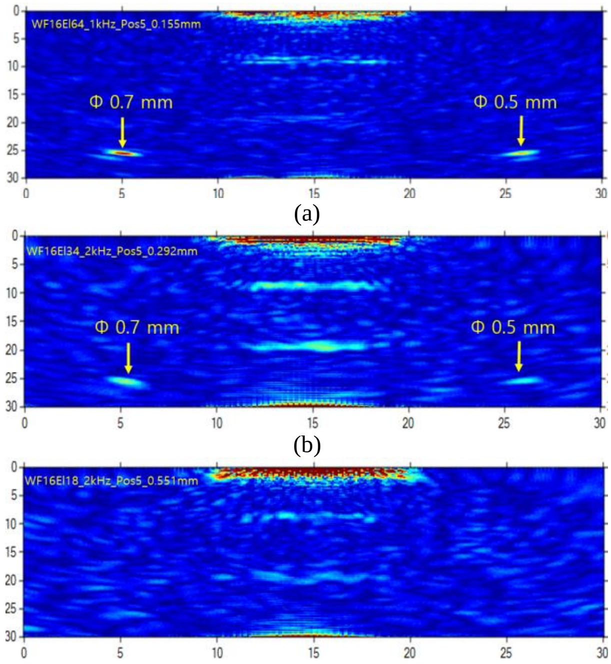

Fig. 4. TFM image for 0.7 and 0.5 mm holes using laser induced phased array ultrasound in test of (a) 64 elements with 1 kHz, (b) 34 elements and (c) 18 elements with 2 kHz

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