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Delay-and-Sum Beamforming Technique on Ultrasonic Propagation Imaging System

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ABSTRACT

The ultrasonic propagation imaging (UPI) system, which is the one of the ultrasonic testing method for NDT & E has advantages of very fast inspection speed and various applications. However, the system may not secures high signal to noise ratio (SNR) of acquired ultrasonic signals because it has used to utilize laser, which have lower excitation energy than other manners. Hence, the UPI system is being required to have improved SNR for enhancement of damage detection and evaluation ability of the system. In this study, we schemed that SNR securing for laser-induced ultrasonic signals by applying delay-and-sum beamforming technique and sensor array to the UPI system. The delay-and-sum beamforming technique, which is the one of spatial filtering, is able to amplify SNR of signals that reach to sensor array by being propagated from specific angle. The digitizer, which is the one of the ADC that support multi-channel acquisition with multiple sensors are integrated to the UPI system to apply delay-and-sum beamforming. The algorithm has been validated through comparisons between the 1-D time domain signals of raw and beamforming.

1. INTRODUCTION

For ultrasound testing method, low signal to noise ratio (SNR) of ultrasonic signals not in laboratory environments but in real world environments has been issued in long standing.

Low SNR problems in cases of investigations for raw metallic plate or simple

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structures are able to be solved by analog or digital filtering, but it requires much efforts to make a selection of optimized condition for noise elimination. Signal filtering conditions determined in laboratory environments may not be appropriate to real world environments, thus it has possibility to fail to analyze acquired ultrasonic signals due to low SNR.

In this article, we have introduced ultrasonic propagation imaging (UPI) system (Lee, 2010), which is the one of ultrasonic testing system and beamforming technique that is the one of spatial filtering (Jarmer, 2014). We also have showed that beamforming technique may be able to be a solution for low SNR problems by presenting experimental results generated by UPI system and beamforming technique.

2. BEAMFORMING TECHNIQUE AND UPI SYSTEM

The UPI system shown in Fig. 1 is able to generate ultrasonic wave by irradiating laser beam in high speed up to several ten kilohertz and acquire these simultaneously. Recently, various damage visualization techniques based on UPI system have been studied, and these are aimed to enhance damage visibility by eliminating laser-induced wave components in raw ultrasonic signals.

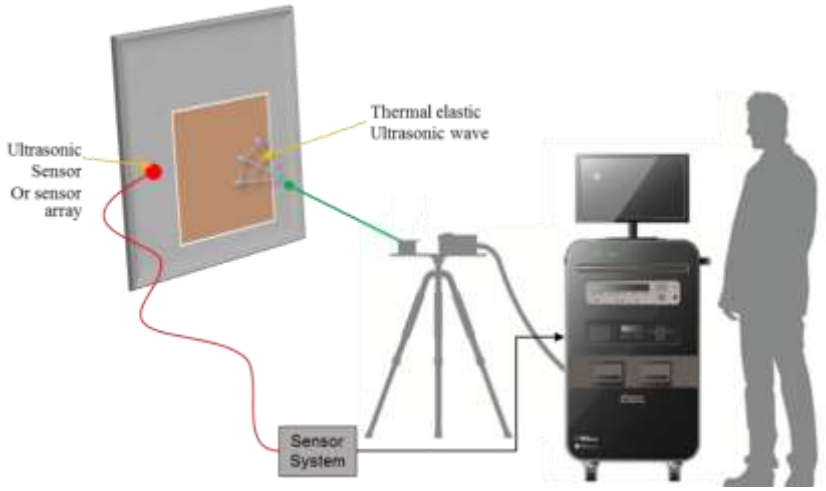

Fig. 1.Schematic of ultrasonic propagation imaging (UPI) system

Beamforming technique introduced in this article is aimed to enhance visibility of defects by increasing SNR of raw signals and offers much greater analyzability for other signal processing methods equipped in the UPI system. This technique performs time delay calculation based on geometry of sensor array and matching phase of signals by delaying arrival time of signals acquired through each elements of sensor array. As a result, laser-induced ultrasonic wave components, which are periodic along to space domain, are amplified, and level of random noise components in raw signals are decreased relatively.

Traditional beamforming applications have been aimed to enhance SNR of only single-source signal. However, the suggested solution is able to present video or image results of ultrasonic propagation patterns in higher SNR to inspection manpower.

3. ALGORITHM VALIDATION AND STATISTICAL ANALYSIS

An experimental setup shown in Fig. 2(a) was configured to show the enhancing effects of SNR and ability for damage visualization of the UPI system. Aluminum plate, which has 4 mm of thickness with artificial close defect described in Fig. 2(b) was used, and the UPI system implemented scanning within the $152\ \mathrm{mm} \times 152\ \mathrm{mm}$ of scan area with scan interval $0.5\ \mathrm{mm}$. Sensor array was configured with seven of sensor elements linearly. All analog signals have been filtered through the band-pass filtering in range $0.2\ \mathrm{MHz}$ to $0.6\ \mathrm{MHz}$ and converted to digital signal with $5\ \mathrm{MSam/sec}$ of sampling rate. In this study, we aimed on $0.35\ \mathrm{MHz}$ to $0.45\ \mathrm{MHz}$ of frequency components.

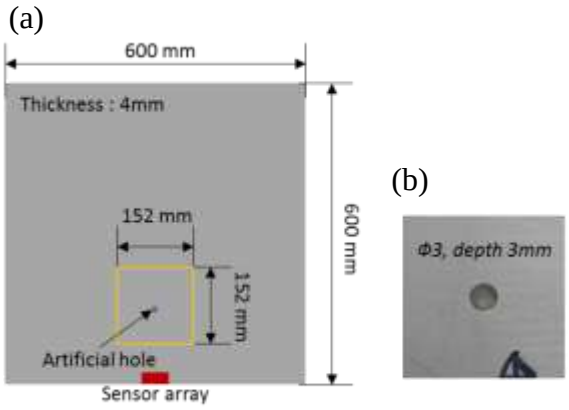

Fig. 2 Details of experimental setup (a) Scan area and array locations (b) artificial hole

Fig. 3 shows that normalized 1-D time domain signals for raw signals with single sensor and beamforming-processing at (75, 100) of scan grid point. SNRs for each signals were calculated as -0.46 dB and 13.61 dB respectively and it is clear that SNRs have been increased by approximately 14 dB.

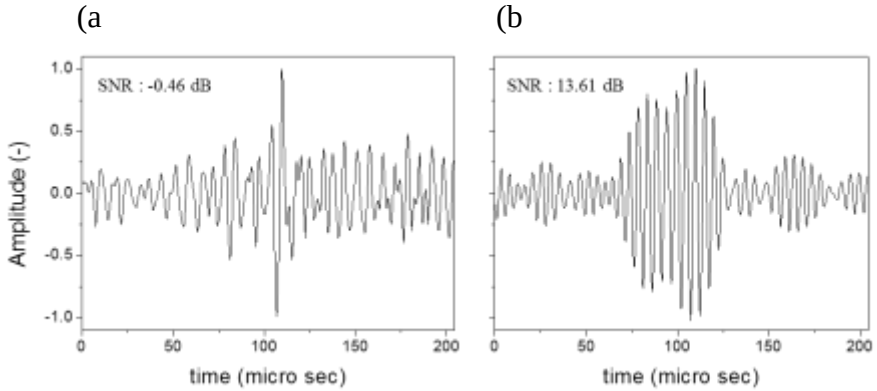

Fig. 3 Normalized 1-D time domain signals of (a) single sensor (SNR: -0.46 dB) (b) sensor array with beamforming-processing (SNR: 13.61 dB)

Freeze-frames of ultrasonic wave propagation imaging (UWPI) video clips generated using raw signals of single sensor and beamforming-processed signals are presented in Fig. 4(a) and (b). By beamforming processing, amplitude of overall signals were

decreased, and back-scattering wave, front-scattering wave and confining wave components induced by the artificial hole have been able to be observed due to SNR increase. Thus, it is clear that beamforming processing for inspection results from the UPI system is able to secure visibilities of damage or damage-induced wave components.

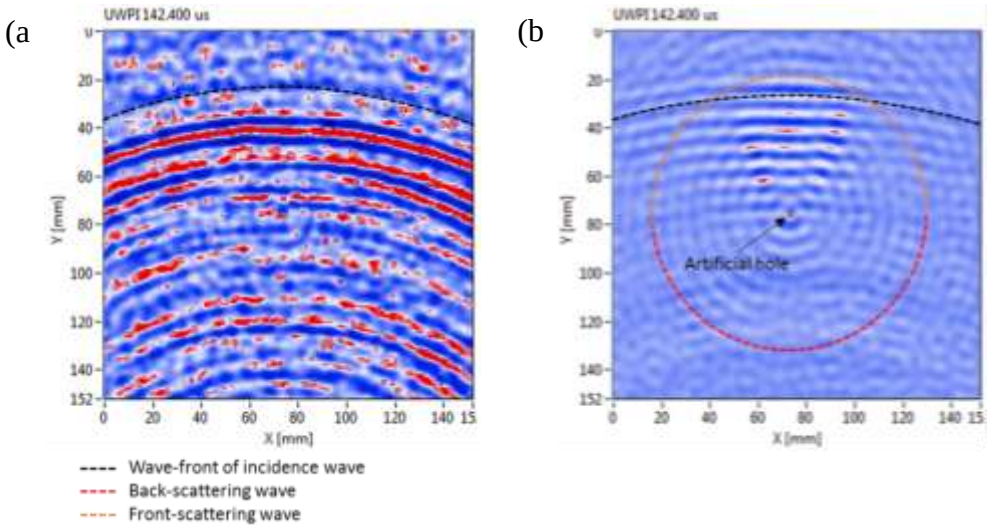

Fig. 4 Freeze-frames of UWPI video clips with (a) single sensor, raw signals (b) sensor array, beamforming-processing, at 142.4 micro second

4. CONCLUSION

In this study, we have introduced SNR enhancing method with delay-and-sum beamforming technique as a solution to overcome low SNR problems in traditional ultrasonic testing on NDT & E. Descent of noise level was observed by comparison between freeze-frames of UWPI video clips generated with signals from single sensor and linear sensor array. By presenting SNRs of time domain signals at specific point together, we showed that beamforming technique with the UPI system is promising approach for damage inspection in real world.

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