Development of an Integrated Multi-channel Ultrasonic System for Online Structural Health Monitoring of Large Structures

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1. Introduction

Structural health monitoring (SHM) has becoming one of important issues in the maintenance of various structures such as large steel plates, vessels, and pipes in nuclear power plants. Especially, ultrasonic guided waves have been proposed by many researchers for promising SHM applications because they have ability to travel long distances in the target structures [1, 2]. However, the interpretation of guided wave signals obtained from complex geometrical structures is very difficult. Recently, to address such difficulty, computed tomography (CT) and array methods have been proposed for generating two dimensional images of plate-like structures using spatially distributed ultrasonic transducers [3]. We developed an integrated multi-channel ultrasonic system that can handle array transducers and carried out experiments by using the developed system to construct CT images of a defect in a specimen.

2. Development of a SHM system

The developed system is a computerized multi-channel system that can handle array transducers. It consists of an ultrasonic analog module, an ultrasonic digital module, and a signal processing/control module as shown in Fig. 1.

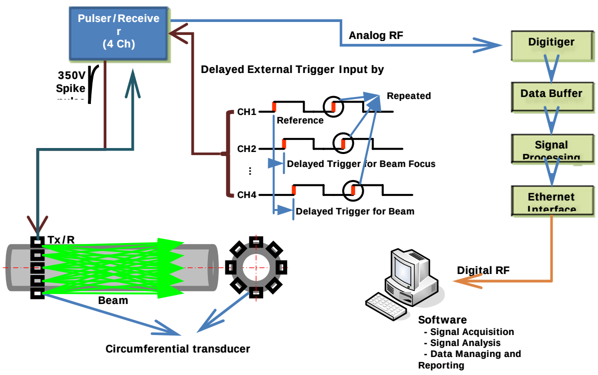

Fig. 1. Schematic diagram of online structural health monitoring system for the structures in a nuclear power plant

The ultrasonic analog module sends and receives ultrasonic guided waves. It consists of array transducers and pulser/receiver. The ultrasonic digital module converts received analog signal to digital signal and sends digitized signals to the processing/control module. The signal processing/control module controls the ultrasonic analog/digital modules and displays information including received signal waveforms. In Fig. 2, (a) is pulser/receiver module, (b) is communication module, and (c) is analog-to-digital conversion and control module.

(a) (b) (c)

Fig. 2. (a) Pulser/receiver module (b) communication module (c) ADC & main controller module

The software of the system consists of a HW control module, a signal processing module, a signal display module, a data handling module, and a capture module. The HW control module manages the operation of 4-channel pulser/receiver, an A/D converter, and a trigger delay circuit. It also controls sending, receiving, and focusing of signals. The signal processing module performs image mapping, time-delay calculation, and post processing of signals such as Short Time Fourier Transform. The signal display module operates the display of the received signals. The data handling module manages data storage and loading. Finally the capture module performs image-capture function of the display on the computer monitor screen.

3. Experiments

We carried out an experiment to validate the performance of the developed system. The purpose of the experiment is to construct a 2-D image based on computed tomography method using array guided waves obtained from spatially distributed ultrasonic transducers. Two aluminum plate specimens were used for the experiment. The size of the specimens is 1000mm x 1000mm. One specimen has a hole-type defect in the center, and another has no defect. Measurements were made by using an array of four ultrasonic transducers. The transducer's center frequency is 0.5 MHz, and sampling rate is 100 MHz. Table 1 shows dimensions of the specimen, transducer locations, and hole-type defect location.

Table 1. Summary of plate dimensions, transducer locations, and hole-type defect location

Dimensions (mm)	Thin Plate Specimen
Thickness	2
Position of Transducer #1	(300,300)
Position of Transducer #2	(700,300)
Position of Transducer #3	(700,700)
Position of Transducer #4	(300,700)
Hole Diameter	5
Position of Hole	(500,500)

Six waveforms were recorded from each specimen. These waveforms correspond to the six possible transmission pairs (1-2, 1-3, 1-4, 2-3, 2-4, 3-4). Fig. 3 shows differenced signals from all transducer pairs between defected specimen and undamaged specimen. These differenced signals were used to construct 2-D CT images of the specimen.

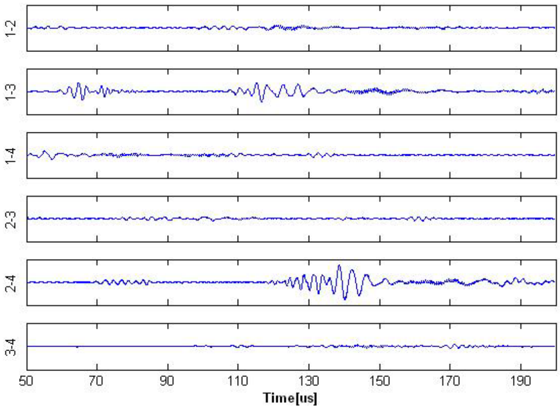

Fig. 3. Differenced signals from all transducer pairs between defected specimen and undamaged specimen

The CT images of the defected specimen can be constructed by using the following equations.

$$c_g = \frac{\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}{t_{ij}} \quad (1)$$

$$t_{ij}^f = \frac{\sqrt{(x_i - x_f)^2 + (y_i - y_f)^2} + \sqrt{(x_i - x_f)^2 + (y_i - y_f)^2}}{c_g} \quad (2)$$

$$s_{xy}(t) = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} d_{ij}(t - t_{ij}^f) w(t - t_{ij}^f) \quad (3)$$

In these equation, $(x_i - x_i)$ are the coordinates of transmitting transducer #i, $(x_j - x_j)$ are those of receiving transducer #j, and $(x_f - x_f)$ are those of a potential defect location, c_g is the group velocity, t_{ij} is the time for the direct arrival from transducer #i to transducer #j, t_{ij}^f is the time from transducer #i to the flaw and then to transducer #j, d_{ij} is the differenced signal form transducer pair (i-j), and w(t) is a windowing function. The group velocity of guided waves can be calculated from the time of the direct arrival as per Eq. (1). And then the time of a scattered signal from a defect can be calculated as per Eq. (2). The image of the defect in the specimen can be constructed by adding all the scattered signals as per Eq. (3).

The measured group velocity was 3.2mm/μs and A_0 mode of Lamb wave in this experiment. Fig. 5 shows the computed tomography image obtained from the experiment.

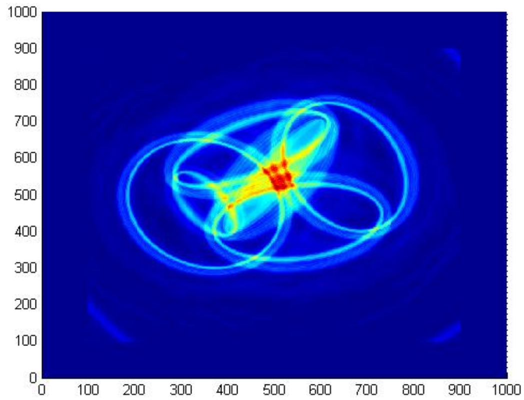

Fig. 5. CT image of specimen

In this experiment, we identified the performance of the developed multi-channel ultrasonic monitoring system and guided wave tomography algorithm.

4. Summary

We developed a computerized SHM system using ultrasonic guided wave technology. The system has ability to carry out necessary functions for the online monitoring of plates and pipes in nuclear power plants. We also studied guided wave tomography algorithm, and the experimental results showed that the developed system has possibility for online SHM of some structures in nuclear power plants.

REFERENCES

[1] J.L. Rose, Standing on the Shoulders of Giants: An example of guided wave inspection, Materials Evaluation, Vol. 60, pp. 53-59, 2003

[2] P.Cawley, M.J.S. Lowe, D.N. Alleyne, B. Pavlakovic, and P. Wilcox, Practical long range guided wave testing: application to pipes and rails, Materials Evaluation, Vol. 61, pp. 66-74, 2003.

[3] H. Gao, Y. Shi and J.L. Rose, Guided wave tomography on an aircraft wing with leave in place sensors, Review of Progress in QNDE, 24B, pp. 1788-1794, 2005.