Wavelet-based Wavenumber Filtering for Damage Detection with a Scanning Laser Sensing System

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ABSTRACT

This paper describes the use of wavelet-based wavenumber filtering for damage detection with a signal-frequency standing wave excitation on thin plate structures. Using a single, fixed frequency excitation from a mounted piezoelectric transducer, the full standing wave-field could be obtained using a Laser Doppler Vibrometer (LDV) with a mirror-tilting device. After scanning, a wavelet-based wavenumber filtering is performed to determine dominant wavenumber components, which could be used for indicative of structural damage. Mapping processes based on the wavelet-based wavenumber filtering is then carried out for damaged area visualization. To demonstrate the proposed techniques, several experiments are performed on thin walled structures with several different types of damage (corrosion, debonding). The results demonstrate that the techniques are very effective in localizing damage with the potential for the improved speed and the performance for damage detection.

1. INTRODUCTION

In this paper, we use a non-contact sensing technique using Laser Doppler Vibrometer (LDV) and a mirror tilting system with a mounted piezoelectric actuator to provide an ultrasonic wave to a structure. Recently, the use of standing waves, instead of traditional using traveling waves, is proposed (Flynn. E. B, 2013, 2014).

Previous studies demonstrate the advantages of this method: 1) Energy is effectively “pumped” into structure, resulting in the higher magnitude of waves, 2) The delay time to wait until previous waves completely die out is not required for continuous measurements, 3) Only a few cycles of wave measurements are sufficient to capture the wave behaviors at each scanning point.

The use of wavelet to detect damage is proposed in many works. Rucka, M (2006) showed that the continuous wavelet transform could detect damage with various scale factors. Based on these studies, our investigation starts to clearly visualize the damage on structures. We use the continuous wavelet transform as a filter to visualize the damaged areas with wavenumber components.

To demonstrate the concept, several experiments are conducted with thin aluminum plates.

2. ALGORITHM

This damage visualization technique based on 2-D wavelet transform consists of two steps. The first step is a laser scanning process to obtain the steady-state response, and the next is to apply a wavelet-based signal processing tool to visualize the damage.

2.1. Laser Scanning System

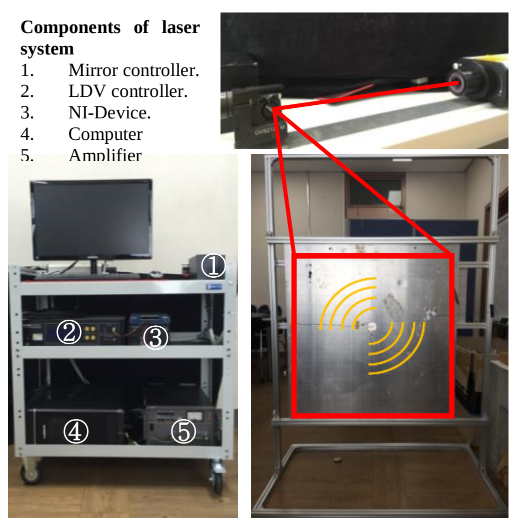

Figure 1. Laser scanning system components.

A laser scanning system for full wave field measurements consists of the following components, 1) A mirror-tilting system to control the position of laser sensing points, 2) Laser Doppler Vibrometer as a sensing device, 3) Data acquisition device to generate an ultrasonic wave and to measure subsequent structural responses, 4) A signal processor and 5) An amplifier. A piezo transducer is attached to the surface of a plate and generates a standing wave at high frequency (> 50 kHz). Because of standing wave excitations, a structure experiences the steady state responses, which are measured in the size of T x N x M by the system, where T is the time data of each sensing point, and N and M are the number of spatial points in the x and y directions. The excitation frequency is normally set at higher than 50 kHz with the sampling frequency of 1MHz. Once structural responses are measured, the steady-state response, $r(x,y)$ of the excitation frequency is extracted by applying Discrete Fourier Transform. Because a steady-state response at the excitation frequency eliminates other frequency components, high signal to noise ratio could be obtained.

$$r(x,y) = \frac{1}{T}\sum_{t=0}^{T} v[x,y,t]exp(-j2\pi ft) \qquad (1)$$

2.2. Damage Visualization using 2-D wavelet

Damage visualization using 2-D wavelet transform starts with the response shown in figure 2, which is obtained by laser scanning.

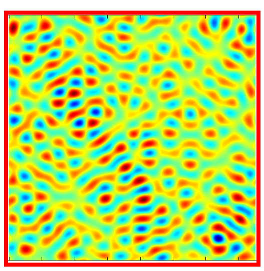

Figure 2. Steady-state response

2-D continuous wavelet transform with various scales is then applied to this steady-state response. A three dimensional data is obtained by rearranging X and Y in the spatial domain, and S in the wavelet scale domain.

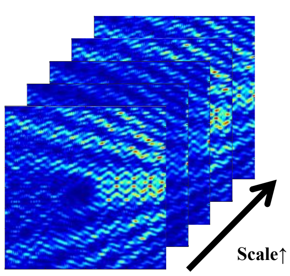

Figure 3. 2-D wavelet transform with various scales

After then, at each spatial point, the scale which has maximum amplitude from this matrix is found. The final step is the transformation of the scale to the wavenumber. With this signal processing procedure, we could detect the damage in a structure by identifying dominant wavenumber components.

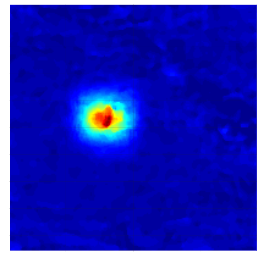

Figure 4. Damage visualization result

3. EXPERIMENT

To demonstrate proposed technique, several experiments are conducted with Al plates, which contains different types of defects.

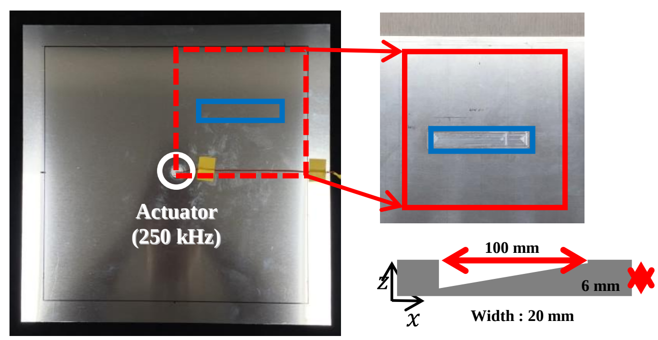

Figure 5. Al plate with continuous damage

The experiment was performed with an aluminum plate of $350{\times}350{\times}6$ mm. As depicted in figure 5, a defect of $100{\times}20{\times}0{\sim}5$ mm size, was introduced to one side of the structure. The excitation frequency was set as 250kHz and the measurements were taken in the area of $150{\times}150$ mm at the spatial resolution of 0.5 mm. Figure 6 shows the damage visualization result using the proposed technique.

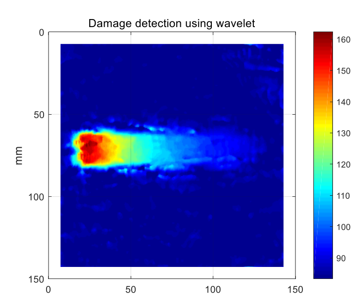

Figure 6. Damage visualization result

As shown figure 6, the proposed damage visualization technique could detect damage which has a continuous defect. It shows the trend that, as damage depth become larger, there are corresponding changes in the wavenumber.

4. CONCLUSION

The damage detection technique, which uses 2-D wavelet transform, is developed and tested. The proposed technique has following advantages: 1) Signals with high SNR could be achieved because energy is effectively pumped into a structures, 2) It does not require synchronization between excitation and measurement, 3) A few data are enough to capture wave's behavior and 4) Robust damage visualization is possible by utilizing a wavenumber feature. For validation of the proposed technique, experiments are conducted to an aluminum plate. The result demonstrates that the use of 2-D wavelet transform is very effective to evaluate several types of damage on thin-walled structure.

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