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Defect detection of composite material using resonance frequency identification by spatial spectral entropy for non-contact acoustic inspection

非接触音響探査法のための SSE 解析の共振周波数識別による複合材料の欠陥検出

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1. Introduction

In our noncontact acoustic inspection[1-4], a method to remotely detect and visualize internal defects of composite materials, such as concrete, has been studied using acoustic excitation and a scanning laser Doppler vibrometer. So far, the spatial spectral entropy[4] (SSE) has been used to detect the resonance frequency band of internal defects in concrete. Acoustic defect images were obtained clearer by narrowing down the visualization frequency range to the resonance frequency range.

From the experimental results for circular cavity or peeling defects inside the concrete, acoustic image of internal defect was tried to be visualized with a combination of vibrational energy ratio[1-2], SSE (spatial spectral entropy), spectral entropy[2-3], spectral flatness, or independently.

2. Experimental setup and concrete wall specimen with a circular cavity defect

Strong aerial plane waves are emitted from a long-range acoustic device (LRAD; LRAD corp., LRAD-300X) to the measurement surface about 5 m away and the surface are acoustically excited (Fig.1).

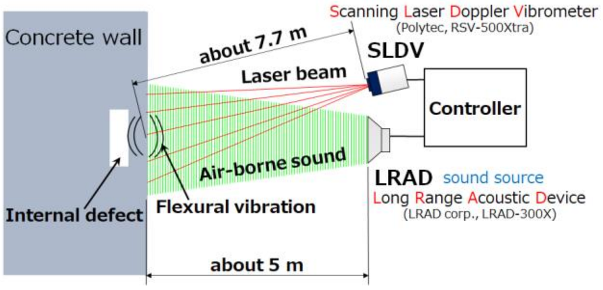

Fig. 1　Experimental setup.

A scanning laser Doppler vibrometer (Polytec, PSV-500Xtra scanning vibrometer) are installed at a distance of about 7.7 m from the measurement surface, and the two-dimensional vibration velocity distribution on the measurement surface was measured. After time-frequency gate processing to reduce noise from surroundings, vibration velocity spectrum was calculated. Fig. 2 shows the shape and embedded depth of a circular cavity defect.

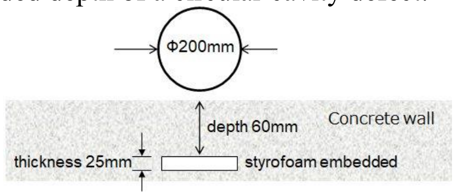

Fig. 2　Shape and embedded depth of a circular cavity defect.

3. Principles

3.1 Spectral Entropy

Spectral entropy is a feature that expresses the whiteness of a signal and is expressed as in Eq. (1).

$$H = -\sum_{f} P_f \log_2 P_f\,, \qquad P_f = \frac{S_f}{\sum_f S_f} \qquad (1)$$

In our noncontact acoustic inspection, the spectrum of each signal is regarded as a probability distribution and information entropy is calculated.

3.2 Spatial Spectral Entropy (SSE)

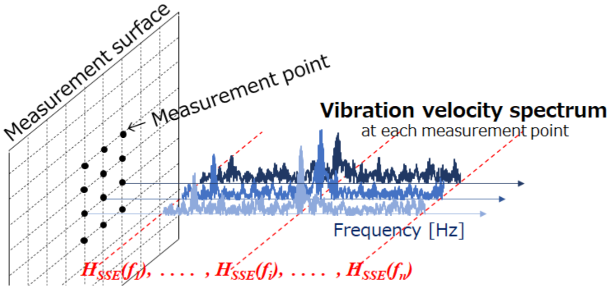

Fig. 3　Principle diagram of SSE.

SSE can detect not only the resonance frequency of internal defects but also the resonance frequency of a laser head of SLDV. SSE[4] is defined by the following equation.

$$H_{SSE}(f) = -\sum_{i=1}^{m}\sum_{j=1}^{n} P_{i,j}(f)\, log_2\, P_{i,j}(f) \qquad (2)$$

$$P_{i,j}(f) = \frac{S_{i,j}(f)}{\sum_{i=1}^{m}\sum_{j=1}^{n} S_{i,j}(f)}$$

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Where $H_{SSE}(f)$ is spectral entropy extended to real space. $S_{i,j}(f)$ is the frequency component of power spectrum of vibration velocity at each measurement point $r_{i,j}$. $P_{i,j}(f)$ is probability that $S_{i,j}(f)$ exists in the measured plane. Therefore, $H_{SSE}(f)$ indicates the information entropy calculated for the frequency f component of vibration velocity spectrum at all measured points.

3.3 Spectral Flatness

Spectral flatness is a measure used in digital signal processing to characterize the audio spectrum. It provides a way to quantify the degree to which it is more like a tone of sound than a noise-like sound. Spectral flatness is expressed by the following equation.

$$Spectral\ flatness = \frac{\sqrt[N]{\prod_{n=0}^{N-1} x(n)}}{\frac{\sum_{n=0}^{N-1} x(n)}{N}} = \frac{exp\left(\frac{1}{N}\sum_{n=0}^{N-1} ln\ x(n)\right)}{\frac{1}{N}\sum_{n=0}^{N-1} x(n)} \qquad (3)$$

High spectral flatness indicates that spectrum has similar power in all spectral bands. Low spectral flatness indicates that spectral power is concentrated in a relatively small number of bands.

4. Results

The vibration velocity spectrum at each measurement point was calculated from the two-dimensional vibration velocity distribution data for a circular cavity defect by noncontact acoustic inspection method. Acoustic image of internal defect was visualized by spectral entropy (Fig.4), or spectral flatness (Fig.5), or vibrational energy ratio to which SSE analysis was applied (Fig.6). The dotted circle near the center of each figure indicates the exact size of circular cavity defect and approximate location of it. The numerical value on the right side of a dot in each acoustic image indicates the measurement point number.

Spectral entropy is an index for evaluating whiteness. On the other hand, spectral flatness is an index for evaluating tone signals and noise. As shown in Figures 4 and 5, in a circular cavity defect (diameter 200 mm, burial depth 60 mm), the position and existence of the defect can be detected by either spectral entropy or spectral flatness.

Since the resonance frequency band due to an internal defect can be found by SSE analysis, the acoustic image of Fig. 6, visualized by narrowing the analysis frequency range to the resonance frequency range (4000-4250Hz), looks the best of the three. Compared to Fig. 4 and 5, the outline of a circular cavity defect is reproduced larger and more faithfully, and the gradation difference from the surrounding healthy part is large, so the defect image is clearly visualized.

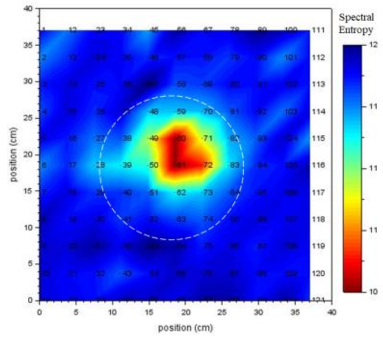

Fig. 4 Acoustic image using spectral entropy.

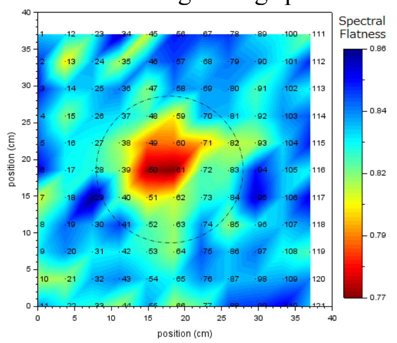

Fig. 5 Acoustic image using spectral flatness.

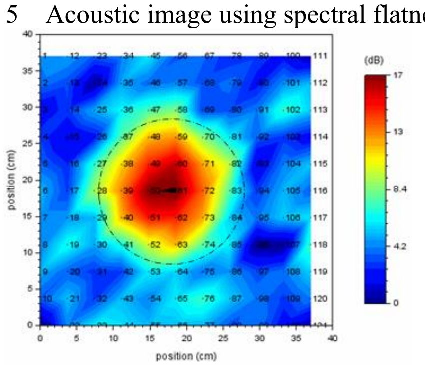

Fig. 6 Acoustic image by vibrational energy ratio applied SSE analysis.

5. Conclusion

As an index of automatically detecting resonance peaks from vibration velocity spectrums, spectral entropy or spectral flatness can be used well. Within these results, an excellent method is to detect a resonance frequency band by SSE analysis and visualize it with vibrational energy ratio calculated in an optimum frequency range.

Acknowledgment

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References

1. K. Katakura, R. Akamatsu, T. Sugimoto and N. Utagawa: Jpn. J. Appl. Phys. **53** (2014) 07KC15.
2. K. Sugimoto, R. Akamatsu, T. Sugimoto, N. Utagawa, C. Kuroda and K. Katakura: Jpn. J. Appl. Phys. **54** (2015) 07HC15.
3. K. Sugimoto, T. Sugimoto, N. Utagawa, C. Kuroda and A. Kawakami: Jpn. J. Appl. Phys. **57** (2018) 07LC13.
4. K. Sugimoto, T. Sugimoto, N. Utagawa and C. Kuroda: Jpn. J. Appl. Phys. **58** (2019) SGGB15.