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Detection of resonance frequency by spatial spectral entropy for noncontact acoustic inspection method

非接触音響探査法のための空間スペクトルエントロピーによる共振周波数の検出

Kazuko Sugimoto[1†], Tsuneyoshi Sugimoto[1], Noriyuki Utagawa[2], and Chitose Kuroda[2]
([1]Grad. School Eng., Toin Univ. of Yokohama; [2]Technical Research Institute, SatoKogyo Co., Ltd.)
杉本和子 [1†], 杉本恒美 [1], 歌川紀之 [2], 黒田千歳 [2] ([1] 桐蔭横浜大院 工, [2] 佐藤工業㈱ 技術研究所)

1. Introduction

In order to detect internal defects of concrete, we have studied noncontact acoustic inspection method and visualized internal defects using two acoustic features (vibrational energy ratio and spectral entropy[1,2)]). In this paper, we propose 'Spatial Spectral Entropy (SSE)' that automatically detects the resonance frequency of internal defects of concrete and simultaneously detect the resonance frequency of the laser head. The value of SSE decreases at the former and rises at the latter, so it is possible to distinguish between them. Note that the proposed method is not limited to the noncontact acoustic inspection method but can be applied to physical quantities measured in a planar curved surface.

2. Spatial Spectral entropy

The spectral entropy (SE) is a feature quantity that expresses the whiteness of a signal, assuming the signal spectrum as a probability distribution and calculating information entropy. SE has a high value in a signal having a uniform spectrum such as a white noise, and a low value in a signal in which the spectrum like a voice signal is not uniform.

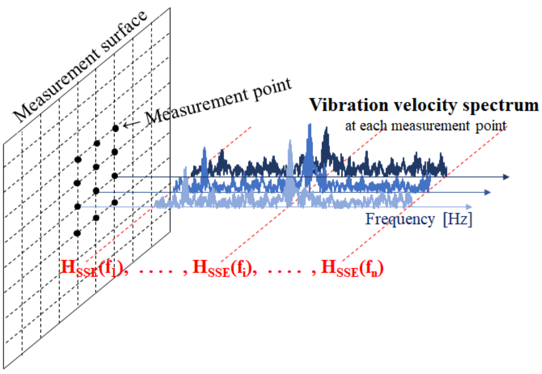


Fig.1. Analysis data direction of Spatial Spectral entropy.

As shown in **Fig.1**, consider the frequency axis of vibration velocity spectrum perpendicular to the measurement plane. Several examples of vibration velocity spectrum at a measured point are displayed from each measured point in the direction perpendicular to the measurement surface. We propose a method of simultaneously detecting not only the resonance frequency of internal defects but also the resonance frequency of a laser head of LDV by calculating the $H_{SSE}(f)$ in the whole planar measurement plane. The SE expanded to such a planar measurement plane is referred to as 'Spatial Spectral Entropy (SSE)' and is defined by the following equation.

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

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

Where $H_{SSE}(f)$ is spectral entropy (a function of frequency f) extended to real space. For example, when considering a two-dimensional measurement plane, the grating measured point $r(x,y)$ is expressed as an array $r_{i,j}$ $(i = 1, m\,;\, j = 1, n)$. $S_{i,j}(f)$ is the spatial frequency component f [Hz] of the power spectrum obtained by performing discrete Fourier transform on the signal measured at the measurement point $r_{i,j}$. $P_{i,j}(f)$ is the probability that the spatial frequency component f [Hz] of the power spectrum at the measurement point $r_{i,j}$ exists within the measurement plane. Therefore, $H_{SSE}(f)$ indicates the information entropy calculated for the frequency component f of vibration velocity spectrum at all measured points.

3. Measurement method

In our noncontact acoustic inspection method, measurement was carried out by a long-range acoustic device (LRAD; LRAD-300X) and a scanning laser Doppler vibrometer (SLDV; Polytec, PSV-500Xtra Scanning Vibrometer). Plane sound waves were radiated from a sound source LRAD to excite the concrete measurement surface. Using SLDV, the vibration velocity distribution on the two-

†kazukosu@toin.ac.jp

dimensional lattice point was measured by automatic scanning. A time-frequency gate process was performed on the obtained data, then after the FFT process, SSE was applied.

4. Measurement Results

Figs.2 and **3** show the results of measuring a circular cavity defect (φ 200, buried depth 60 mm from the concrete surface). **Fig.2** shows the vibration velocity spectrum near the center of the defect. There is a resonance peak due to a circular cavity defect at around 4100 Hz, and a resonance peak of LDV is seen at around 2500 Hz. **Fig.3** shows a result of SSE, there is a resonance peak due to a circular cavity defect at around 4100 Hz, and a resonance peak of LDV is seen at around 2500 Hz. At the resonance frequency of the laser head of LDV, the value of SSE increases and at the resonance frequency due to internal defects of concrete, the value of SSE decreases.

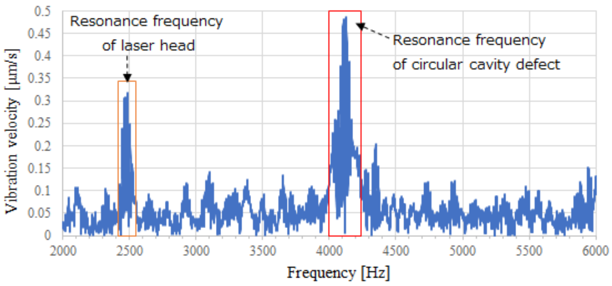


Fig.2. Vibration velocity spectrum at the center of circular cavity defect.

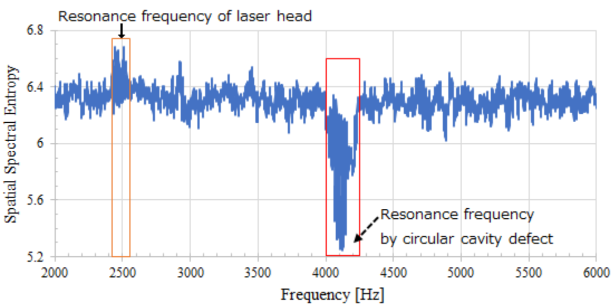


Fig.3. Detected result of resonance frequency by Spatial Spectral entropy.

That is, when attention is paid to a specific frequency of the spectrum, it makes the SSE large because the resonance of a laser head is detected at vibration velocity spectrums of all measurement points. The fact is based on the principle that spectral entropy takes a large value for the whiteness of a signal. On the contrary, when attention is paid to a specific frequency of the spectrum, in case of an internal defect of concrete, since it is rare that the same resonance frequency of an internal defect appears at many measurement points, the value of SSE becomes small.

Figs.4 and **5** show the results of measuring a circular peeling defect (φ 200, buried depth 60 mm from the concrete surface). Comparing **Fig.4** with **Fig.5**, it is found that the SSE accurately detects the resonance frequency of the peeling defect.

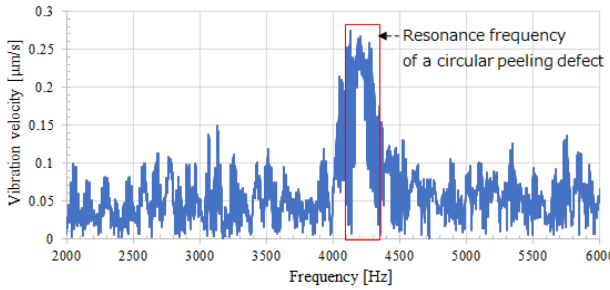


Fig.4. Vibration velocity spectrum at the center of circular peeling defect.

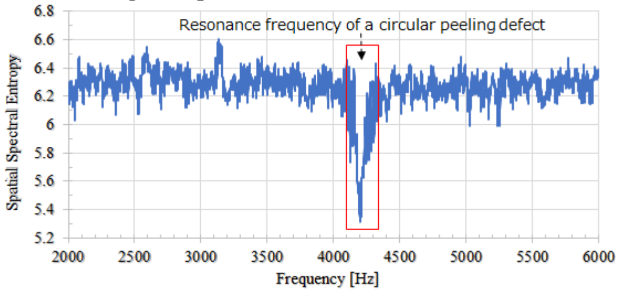
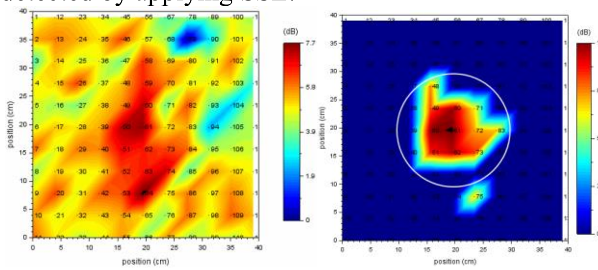


Fig.5. Vibration velocity spectrum at the center of circular peeling defect.

Fig.6 shows an acoustical image of a circular peel defect. (a) shows before applying and (b) shows after applying the results of SSE. From this figure, it can be seen that the defective part can be clearly detected by applying SSE.



(a) Before applying (b) After applying SSE

Fig.6. Imaging of circular peeling defect using Spatial Spectral entropy (SSE = 5.8).

5. Conclusion

We have devised spatial spectral entropy (SSE) and showed that it is possible to automatically detect the resonance frequencies of both the LDV and the internal defect of concrete.

References

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2. K. Sugimoto, T. Sugimoto, N.Utagawa, C.Kuroda, *et al.* : Jpn. J. Appl. Phys., **57** (2018) 07LC13.