Study about the S/N ratio of the multi-tone burst wave for high-speed non-contact acoustic inspection method

Nobuaki Kosuge\(^1\), Kazuko Sugimoto\(^1\), Tsuneyoshi Sugimoto\(^1\), and Noriyuki Utagawa\(^2\)

\(^1\)Graduate School of Engineering, Toin University of Yokohama, 1614 karogane-cho, Aoba-ku, Yokohama, Japan.
\(^2\)E-mail: tm25b10u@ust.toin.ac.jp

Abstract

Since various parameters in the signal were expected to influence the signal to noise (S/N) ratio of the multi-tone burst (MTNB) wave, the influence on the S/N ratio when changing the frequency arrangement within the wave group of the signal waveform was mainly studied. As the frequency arrangement, signal waveforms such as those arranged in order, discretely arranged and frequencies close to higher harmonics are selected as much as possible are prepared, and studies on the S/N ratio using concrete test pieces were conducted. Experimental results show that a MTNB waveform with frequencies closer to the higher harmonics has a higher S/N ratio than that of the waveforms with the other frequency arrangement.

Keywords: non-contact inspection, long distance measurement, scanning laser Doppler vibrometer, long range acoustic device, tone burst wave

1 Introduction

Hammering test has been the mainstream as a method of inspecting cracks and exfoliation that may have occurred in the surface layer of concrete structures. This inspection method is simple in that an inspector hits the concrete surface and does not require expensive measuring equipment. However, it depends on the inspection depends on the experience and age of the inspector in terms of accuracy, and has a disadvantage that inspection is difficult in high-rise facilities such as bridges. Instead of the above method, we have been experimenting a non-contact acoustic investigation method in which both a long range acoustic device (LRAD) and a laser Doppler vibrometer (LDV) are used. It has already been shown that this technique makes it possible to detect defects 5m or more\(^1-4\) away from the object of the inspection and that its accuracy is an accurate as the same accuracy as the hammer method. However, although this method away from a long distance, when we uses the multi-tone burst (MTNB) wave\(^5\) in order to shorten a measurement time, the signal to noise (S/N) ratio tends to be lower compared with that of the single tone burst (STNB) wave\(^6\) which has been conventionally used. Therefore in this study, we observed how the S/N ratio was investigated when the frequency arrangement in the signal waveform was change. Since there is a possibility conceivable that the S/N ratio of the MTNB wave is changed by changing various parameters in the signal.
2 Measurement principles

The fundamental setup of this method is shown in Fig. 1. First, a sound wave is emitted to the measurement object. Next, using the LDV, the vibration velocity of the surface of the object is measured. If a cavity such as a crack or the like exists in the vicinity of the surface of the object to be measured, if a sound wave including a flexural resonance frequency is emitted, a flexural vibration is generated above the defect portion similarly to the hammer method. In the case of concrete, since this resonance frequency is usually in the audible range, excitation by the speaker becomes easy. Therefore, this method utilizes flexural vibration.

![Fig.1 Schematic diagram of measurement principle](image)

3 Multi-tone burst waves

The MTNB waves are the signal waveform which includes multiple center frequencies in a transmission of sound waves. The wave length is below the length of the measurable time zone. The number of the center frequency included in a wave emitted at one time changes with the distance to an object, or the pulse width of one center frequency. However, the measurement time can be shortened by one half or one-third, since the whole rest time becomes shorter compared with a single tone burst wave. A schematic diagram is shown in Fig.2.
Fig. 2 The schematic diagram of the tone burst wave. (a) MTNB, (b) STNB

4 Comparative experiments of S/N ratios

Three kinds of MTNB waves, such as harmonic-type (H-type, in which frequencies as selected to higher harmonics as possible are selected and arranged), discrete-type (D-type, discretely arranged) and continuous-type (C-type, those arranged in order) were used as the MTNB waveforms. For comparison, the conventional STNB wave was also used.

In the Harmonic-type, the frequency arrangement of each MTNB wave is devised to contain a lot of higher harmonics such as the first wave group of 1000, 2000, 3000 Hz, the second wave group of 1200, 2400, 4800 Hz, and the third wave group of 1400, 2800, 4200 Hz. (Depending on the number of frequencies that can be to what and the number of wave groups, all the frequencies placed in a wave group are not necessarily the higher harmonics)

Discrete-type is an arrangement of vibration signals at constant frequency intervals such as the first wave group of 1000, 1600, 2200 Hz, the second wave group of 1200, 1800, 2400 Hz, and the third wave group of 1400, 2000, 2600 Hz.

Continuous-type is so arranged that the first wave group contains of 1000, 1200, 1400 Hz, the second wave group of 1600, 1800, 2000 Hz, and the third wave group of 2200, 2400, 2600 Hz.

The comparison experiments of S/N ratio were conducted under the same condition of the signal waveform, the frequency range of the MTNB wave is set at 2000-6800 Hz, the frequency range of the STNB wave at 2000-6000 Hz, the frequency modulation interval at 200 Hz, the pulse width in 3 ms, and the inter-pulse interval at 50 ms. Table 1 shows the frequency arrangement of the Harmonic-type used in the experiments.
Table.1 Frequency arrangement of Harmonic-type

<table>
<thead>
<tr>
<th>Harmonic-type</th>
<th>1st group</th>
<th>2nd group</th>
<th>3rd group</th>
<th>4th group</th>
<th>5th group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.0</td>
<td>2.2</td>
<td>2.8</td>
<td>3.4</td>
<td>2.4</td>
</tr>
<tr>
<td></td>
<td>4.0</td>
<td>4.2</td>
<td>5.4</td>
<td>3.6</td>
<td>4.8</td>
</tr>
<tr>
<td></td>
<td>3.0</td>
<td>4.4</td>
<td>5.6</td>
<td>3.8</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td>5.8</td>
<td>4.6</td>
<td>3.2</td>
<td>6.2</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td>6.0</td>
<td>6.6</td>
<td>6.4</td>
<td>5.8</td>
<td>5.2</td>
</tr>
</tbody>
</table>

| Continuous-type | 2.0       | 3.0       | 4.0       | 5.0       | 6.0       |
|                 | 2.2       | 3.2       | 4.2       | 5.2       | 6.2       |
|                 | 2.4       | 3.4       | 4.4       | 5.4       | 6.4       |
|                 | 2.6       | 3.6       | 4.6       | 5.6       | 6.6       |
|                 | 2.8       | 3.8       | 4.8       | 5.8       | 6.8       |

| Discrete-type   | 2.0       | 2.2       | 2.4       | 2.6       | 2.8       |
|                | 4.0       | 3.2       | 3.4       | 3.6       | 3.8       |
|                | 5.0       | 5.2       | 5.4       | 5.6       | 5.8       |
|                | 6.0       | 6.2       | 6.4       | 6.6       | 6.8       |

As the measurement time, since the STNB wave transmits the pulse of one frequency 20 times per 50 ms, the time required for transmitting the whole waveform is 1 second (1000 ms). On the other hand, in the case of MTNB waves, since five frequency groups are transmitted one by one at the interval of 50 ms, the time required for the overall waveform transmission is 0.25 seconds (250 ms). The delay time for one data recording of the SLDV is about 200 ms.

5.1 Experimental setup

Experiments were conducted on a concrete test object with circular peeling defects which were made of plastic films with a diameter of 300 mm and a diameter of 200 mm embedded at a depth of 60 mm. The experimental setup diagram is shown in Fig.3. LRAD-300X (LRAD Corp.) was used as a sound source. As the LDV, PSV-500 Xtra (Polytec Corp., semiconductor laser, infrared light 10 mW) was used. The distance between the sound source and the concrete peac e is about 5 m, and the distance between the LDV and the concrete is about 7.0 m. At the time of measurement, the vibration speed of the defective portion was measured by adjusting the maximum sound pressure in the vicinity of the concrete surface to be about 100 dB. The average number of addition is set to 5 times for both MTNB waves and STNB waves.
5.2 Calculation of S / N ratio

The S / N ratio of the vibration velocity spectrum amplitude (VSA) obtained at the center portion of the defect was calculated using the equation (1).

\[
S / N[\text{dB}] = 20 \cdot \log_{10} \left( \frac{\text{VSA}_{\text{peak} \pm 5\text{Hz}}}{\text{VSA}_{2000-3000\text{Hz}}} \right) \quad (1)
\]

\( \text{VSA}_{\text{peak} \pm 5\text{Hz}} \) represents the average amplitude value of the peak value ± 5 Hz of the vibration velocity spectrum. \( \text{VSA}_{2000-3000\text{Hz}} \) represents the average amplitude value of 2000 Hz - 3000 Hz in the vibration velocity spectrum. (The resonance of the defective part \( \phi_{200-60} \) is about 4200 Hz and \( \phi_{300-60} \) is about 2800 Hz.).

5.3 Experimental results

The results of the experiments are shown in Fig.4. A blue bar represents \( \phi_{200-60} \) (Dia. 200mm, depth 60mm), a red bar represents \( \phi_{300-60} \). Concerning \( \phi_{300-60} \), the S/N ratio is between by a few dBs at the H-type than at the D or C-type. The reason why the experimental results were different in the two simulated defects is considered to be that the frequency arrangement of H-type was not necessarily arranged at higher harmonic multiples. The resonance frequency of \( \phi_{300-60} \) was found to be and the 2800 Hz. Higher order harmonic frequencies were in the same wave group. On the contrary, the resonance frequency of \( \phi_{200-60} \) was 4200 Hz. And there were no higher harmonic frequencies in the same wave group (Table.1 reference).
6 Summary

The experimental results showed that the S/N ratio was improved by several dB in the H-type compared with that of other frequency arrangement types only when the resonance frequency was located near to the higher harmonic frequencies.

Therefore, in order to obtain the S/N ratio improvement in the higher harmonics, it is necessary that all frequency ranges have to be combined with higher harmonics although the waveform becomes longer.

References


