Nondestructive Inspection Using Transient Vibration Excited by Acoustic Radiation Force

Koko Kitamura‡, Hideyuki Nomura (Univ. of Electro-Comm.)

1. Introduction

When an amplitude modulated ultrasound enters an object, dynamic acoustic radiation force generates on the surface and vibration at the modulation frequency is induced. By acquiring the steady response to the vibration, an image based on vibration characteristics of the target is obtained[1,2] or its mechanical property is examined[3].

For imaging, selecting an appropriate excitation frequency will improve the contrast. However, resonant frequencies of the target are sometimes unpredictable. In such a case, a wideband acquisition would be helpful because there is no need to determine the frequency.

The purpose of this study is to propose nondestructive inspection using transient response excited by acoustic radiation force. First, vibration characteristics of the target obtained by steady and transient responses were compared. Then, a one-dimensional scanning using transient response was performed for an application to nondestructive inspection.

2. Acoustic radiation force (ARF)

When a sound wave enters an object whose acoustic impedance is different from that of the propagation medium, acoustic radiation force occurs on the surface. Considering a single frequency sound wave entering an object, ARF is given by

$$F_{\mathrm{rad1}} = \frac{SP_0^2\left(1+|R_\mathrm{p}|^2\right)}{2\rho c^2} \tag{1}$$

where S is area, P_0 is amplitude of sound pressure, R_p is reflectance of sound pressure, ρ is density, c is sound speed. In this case, ARF is a constant value.

On the other hand, for an amplitude modulated signal with modulation frequency Δf, ARF is described as

$$F_{\mathrm{rad2}} = \frac{SP_0^2\left(1+|R_\mathrm{p}|^2\right)}{4\rho c^2}[1-\cos(2\pi\Delta f t)] \tag{2}$$

where t is time. Eq. (2) indicates ARF periodically changes in time at the frequency Δf.

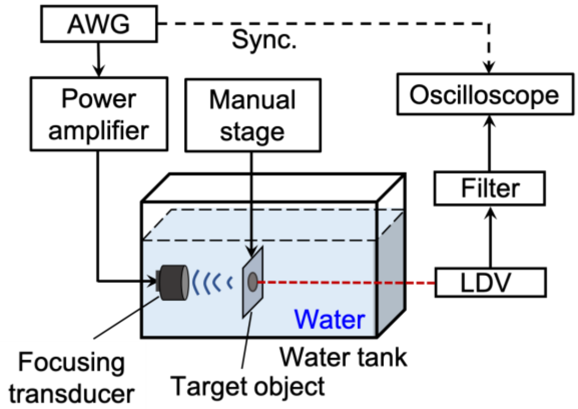

Fig. 1 Experimental setup

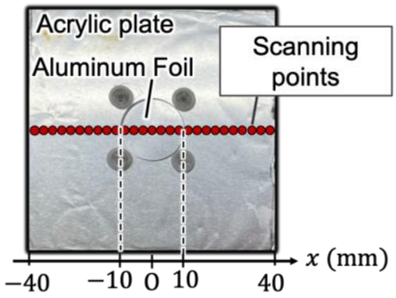

Fig. 2 photograph of the target object and scanning points.

3. Experimental setup and target object

Experiments were performed in a water tank. **Figure 1** shows the experimental setup. The photograph of an aluminum foil as a target is shown in **Fig. 2**. The aluminum foil was fixed by two acrylic plates which have a hole with a diameter of 20 mm in the center. The target was placed at the maximum sound pressure distance of a focusing ultrasound with a resonance frequency of 2.6 MHz and a curvature radius of 10.1 cm. In these experiments, beam diameter at the target position was 2.4 mm.

4 Acquisition of vibration characteristics

4.1 Steady response method

Tone burst signals at the frequency of 2.6 MHz $\pm\,\Delta f/2$ (length 120 ms, cycle period 300 ms and $\Delta f = 0.3$-4 kHz) were generated with an arbitrary waveform generator. A focusing

E-mail: koko.kitamura@uec.ac.jp, h.nomura@uec.ac.jp

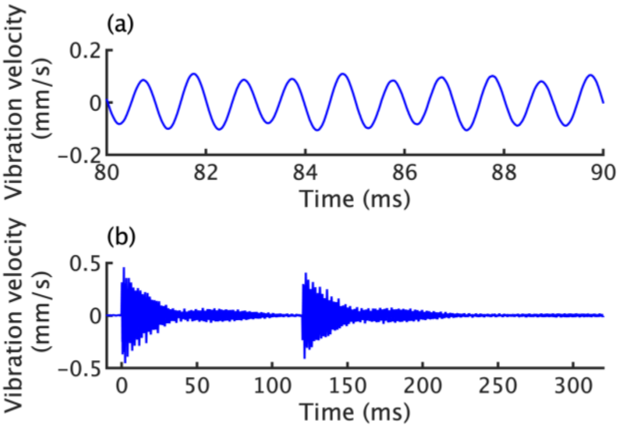

Fig. 3 Waveform of vibration velocity. (a) steady response at $\Delta f = 1$ kHz (b) transient response.

transducer emitted the sum of two signals after it was 50 dB amplified by a power amplifier. Root-mean-square (RMS) value of incident sound pressure was 386 kPa. Vibration velocity of the aluminum foil at $x = 0$ was measured by a laser Doppler vibrometer (LDV) and sent to an oscilloscope through an octave bandpass filter with the center frequency Δf.

4.2 Transient response method

Tone burst ultrasound at the frequency of 2.6 MHz (length 120 ms and cycle period 500 ms) was radiated from the transducer. RMS value of incident sound pressure was 386 kPa. Vibration velocity at $x = 0$ was measured by a LDV and observed by an oscilloscope through a bandpass filter of 0.2-10 kHz.

5. One-dimensional scanning by transient response

Scanning points are described as Fig. 2. Frequency, length and cycle period of tone burst ultrasound were 2.6 MHz, 180 ms and 1 s, respectively. RMS value of incident sound pressure was 483 kPa. Vibration velocity measured by a LDV was sent to an oscilloscope through a high pass filter of 30 Hz. The target was moved by a manual stage. Scan range and interval were set to $-39\text{ mm} \le x \le 39$ mm and 3 mm, respectively.

6. Results and Discussions

Figure 3(a) shows a waveform of vibration velocity when $\Delta f = 1$ kHz. The object vibrated at Δf. We got vibration characteristics from the frequency component of each Δf in the steady response method.

Transient vibration of the target is shown in Fig. 3(b). Transient vibrations were observed at rising (0 ms) and falling (120 ms) of the signal. Vibration characteristics was obtained by Fourier transform of the transient response.

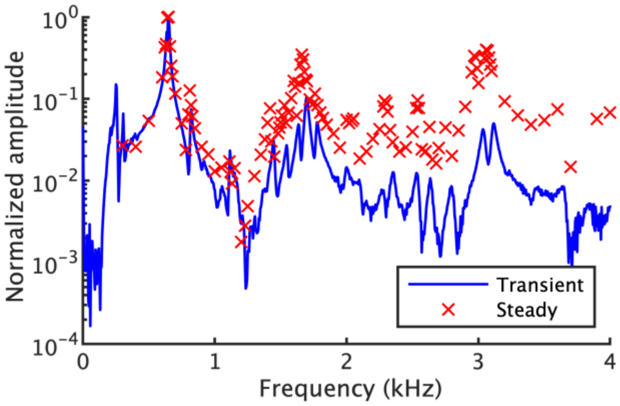

Fig. 4 Comparison of frequency characteristics.

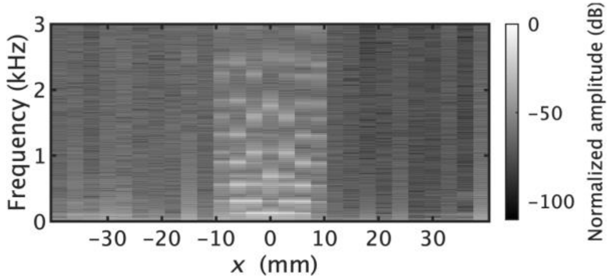

Fig. 5 Distribution of vibration characteristics.

Figure 4 shows comparison of vibration characteristics obtained by steady and transient responses. Both frequency characteristics are in good agreement. It is found that vibration characteristics can be acquired by the transient response method.

A distribution of vibration characteristics using transient response is shown in **Fig. 5**. In $-10\text{ mm} \le x \le 10\text{ mm}$, the distribution corresponding to the vibration mode of the foil appeared. It is found that a high-contrast image was obtained from the transient vibration of the target.

7. Conclusion

In this study, vibration characteristics obtained by steady and transient responses were compared and they were in good agreement. The image acquired from transient response suggests that the proposed method does not need to select appropriate excitation frequencies to obtain high-contrast images.

Acknowledgment

This work was supported by JSPS KAKENHI Grant Number 22K04135.

References

1. M. Fatemi and J. F. Greenleaf: Science, **280**(1998) 82.
2. B. S. Marció, A. A. Seibert, G. A. Braz, A. A. O Carneiro and R. C. C. Flesch: Ultrasonics, **111**(2021) 106339.
3. D. Mazumder, S. Umesh, R. M. Vasu, D. Roy, R. Kanhirodan and S. Asokan: Phys. Med. Biol., **62**(2017) 107.