Barker-coded Ultrasonic Imaging using Optical Surface Vibration Measurement

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Rapid Communication

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A refined imaging method is proposed that can detect the surface vibration velocity of a sample placed on a vibrating piezoelectric transducer surface in air. The piezoelectric ultrasonic transducer is excited using a Barker-coded voltage signal under a constant-voltage drive to obtain a vibration velocity with the same waveform as a coded ultrasonic signal in the time domain. The coded vibration velocity is detected using a laser Doppler vibrometer and is used to image the object placed on the transducer via cross-correlation. A silicone rubber sheet containing the characters "U" and "S" are imaged under low S/N conditions to confirm the performance of the method. Ultrasonic velocity in sample can also be measured with this system.

Keywords : Surface vibration velocity, Constant-voltage drive, Barker code, Ultrasonic imaging, Shadowgraph imaging

1. Introduction

To date, most ultrasonic imaging has been performed by transmission of ultrasonic waves into an acoustic medium, such as water or biological tissue, and reception of the reflected waves from the object of interest. However, immersion is unsuitable for objects such as electronic devices, where there is the possibility that device deterioration, corrosion and short circuits may occur. For many types of objects, it is preferable to perform the imaging process in air. The scanning laser acoustic microscope (SLAM)[1] is an ultrasonic imaging system that is used in air. However, with the SLAM, it is still necessary to immerse the object under examination in a propagation medium such as water, and the SLAM is a complicated device because of its high operating frequency of around 100 MHz.

In our previous paper, unique measurement-related techniques were proposed, including an excitation method for piezoelectric transducers and vibration velocity and optical data acquisition methods[2]. The core principle of the proposed measurement system is that the output vibration velocity waveform has a similar shape to that of the excitation voltage in the time domain when the piezoelectric transducer is driven at a constant voltage with a time constant τ that is much shorter than the fundamental resonance period T_0 ($=1/f_0$, where f_0 is the resonance frequency) of the piezoelectric transducer[3]. Additionally, the ultrasonic vibration amplitude and phase are constant over the transducer' s surface before the interference components such as the edge wave and internal multiple reflections of the transducer[3,4] are affected. To develop the new ultrasonic imaging method, this universally constant surface vibration velocity (USV) was utilized. Moreover, differences of time delay of the ultrasonic vibration velocity can be used to image the acoustic properties of a sample placed on the transducer[2].

In this paper, we describe an alternative imaging method for development of a new paradigm in ultrasonic imaging. This system introduces a Barker-coded ultrasonic signal to overcome previous difficulties in ultrasonic imaging under low signal-to-noise ratio (S/N) conditions. The usefulness of this method is demonstrated via an experiment that images the characters "U" and "S" on a silicone rubber sheet under low S/N conditions.

2. Expertiment

In the paper 2) and 3), it was confirmed that the vibration velocity waveform on the surface of a piezoelectric transducer is analogous to that of the applied excitation voltage signal in time domain.

Fig. 1 shows a schematic block diagram of the system. The constant voltage signal excitation method is also used in the new trial here.

Under the condition where $\tau/T_0 \ll 0.1$, a seven-length Barker-coded voltage signal train $\{-1, -1, -1, +1, +1, -1, +1\}$ with a time length $T=7\,\mu s$ was generated using an arbitrary waveform generator (Agilent 33500B).

Each signal, whether +1 or −1, has a width of 1 μs. **Fig. 2** shows the seven-length Barker-coded electrical excitation signal. This coded signal was amplified up to ±40 V by a bipolar amplifier (NF HA4101), which has low output impe-

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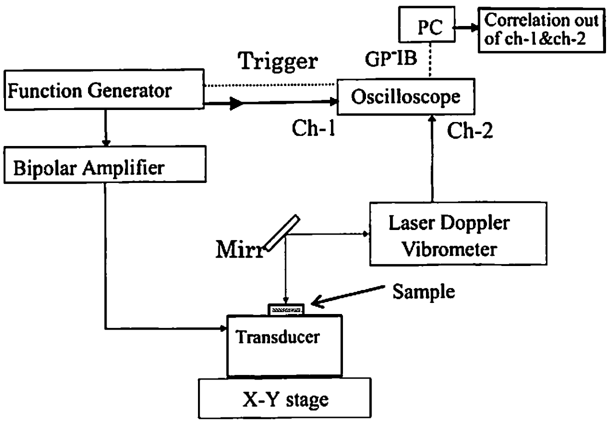

Fig. 1 Schematic block diagram of the system.

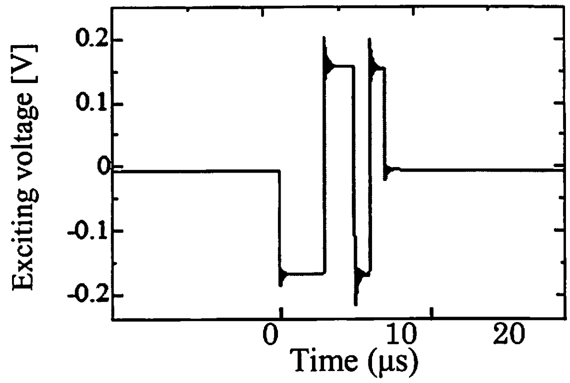

Fig. 2 Barker-coded voltage signal {−1, −1, −1, +1, +1, −1, +1}. This signal was amplified up to ±40 V and applied to the piezoelectric transducer.

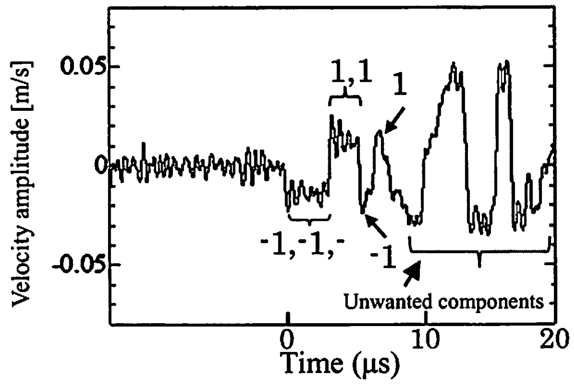

Fig. 3 Vibration waveform of transducers surface excited by the seven-length Barker-coded voltage signal.

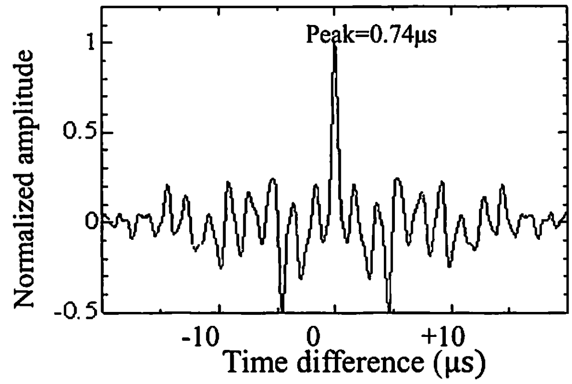

Fig. 4 Cross-correlation of the electrical Barker-coded signal shown in Fig. 2 and the vibration velocity signal shown in Fig. 3. The peak position (0.74 μs) corresponds to the output time delay of the modulator in the Doppler vibrometer.

dance Z_0 of 1.5 Ω. The vibration velocity signal on the surface of the transducer was measured using a laser Doppler vibrometer (Graphtec AT3700) and was stored in the memory of a personal computer (PC) after passing through a digital oscilloscope (Agilent DSO7012B) to perform a cross-correlation with the electrical excitation signal. Peak cross-correlation values were recorded at each position across the transducer surface to obtain the time delay between the two signals. As described later in the paper, these data acquisition processes have been repeated over the transducer surface in the scanning mode

In this experiment, a large-sized cylindrical piezoelectric transducer (Tokin Nepec-21) with a diameter of 60 mm and thickness of 40 mm was used to avoid unwanted interference caused by vibration from the edge and the back side of the transducer[2-4]. The clamped capacitance C_0 was 2020 pF. The resonance frequency f_0 in the thickness direction of the transducer was 26.5 kHz (where $T_0=1/f_0=38\,\mu s$). The ratio τ/T_0 of the time constant τ ($=C_0Z_0=0.003\,\mu s$) to the resonance period T_0 satisfied the condition of being much smaller than 0.1, and thus the constant voltage excitation condition can be satisfied. The uniform surface vibration velocity (USV) can only be generated under this condition[2]. In our system, the cross-correlation was performed using a USV signal and the electrical excitation signal. **Fig. 3** shows the resulting coded vibration velocity on the transducer surface. The Barker-coded ultrasonic vibration signal {−1, −1, −1, +1, +1, −1, +1} followed by unwanted interference components[2-4] is shown in Fig. 3. In general, the vibration velocity waveform and the drive waveform do not match when the piezoelectric transducer does not excited by the constant voltage signal[2]. The unwanted components in the figure do not affect the imaging process because there is no correlation with the electrical excitation signal.

In the experiment, the cross-correlation was calculated to obtain the time difference between these two signals. **Fig. 4** shows the correlation output between the two signals of Fig. 2 and Fig. 3. The output time delay Δt_s of the laser Doppler vibrometer was estimated to be 0.74 μs from the peak position of the main lobe. This time delay corresponds to the time lag of

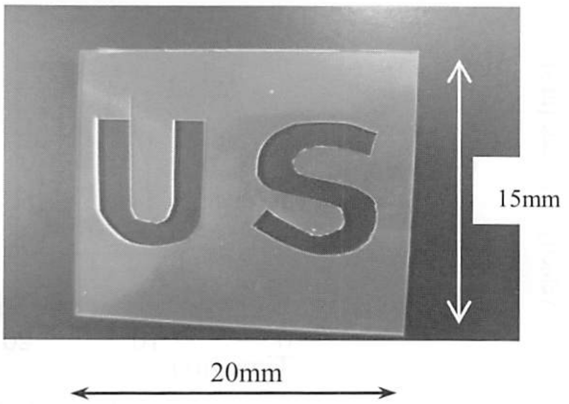

Fig. 5 Imaging target made from silicone rubber containing micro-balloons. The characters were cut out with a knife.

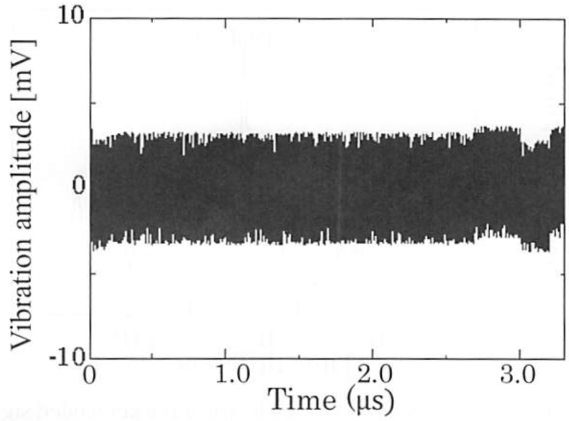

Fig. 6 Vibration velocity waveform obtained from the surface of silicone rubber in which micro-balloons are included inside the rubber sheet[5]. Barker-coded signal is not appeared in the figure.

the output of the demodulator in the Doppler vibrometer, which converts the signal from an optical Doppler component to an electrical velocity signal. In the imaging process, this time lag Δt_s must be subtracted from the results in the case where the sample is placed on the transducer.

3. Imaging using Barker-coded ultrasonic vibration velocity Manuscript length

Fig. 5 shows a sample target made of silicone rubber containing micro-balloons of 0.5% weight[5]. Dimensions of silicone rubber sheet were 15 mm × 20 mm square with a thickness h of 2 mm. The sample target shown in Fig. 5 was affixed to the transducer surface with vacuum grease. The portion of the sheet that contained the characters was cut out. The measurements were performed using a 0.2 mm laser beam scanning interval for the Doppler vibrometer provided by a computer-controlled X-Y stepper motor stage. **Fig. 6** shows the vibration velocity waveform, which has a low S/N of less than 0 dB. From this figure, the Barker-coded signal cannot be identified. Thus, it cannot be imaged in a conventional method or our previous system. **Fig. 7** shows the signal resulting from cross-correlation between the coded excitation signal and the ultrasonic vibration velocity. The peak positions in the cross-correlation signal, which is the time delay between two signals Δt_m as in Fig. 7, were recorded at each of the measurement points on the sample during the scanning process. As described above, the cross-correlation was taken in the PC by shifting, multiplexing and averaging in the memory. It takes about 4 hours to obtain an image since calculation time of 2 seconds was required for each point of the sample placed on the piezoelectric transducer.

Fig. 8 shows the results of the imaging. As the results show, the characters "U" and "S" were imaged with our new system under the low S/N conditions of less than 0 dB as shown in Fig. 6. Because of the high attenuation (>20 dB/mm) of the silicone rubber sheet[5], conventional system and our previous system are unable to perform quantitative estimation of the ultrasonic velocity or the sheet thickness. The effectiveness of the proposed method is also clarified by the fact that such an image cannot be realized using conventional pulse-echo methods. Quantitative measurements such as velocity or

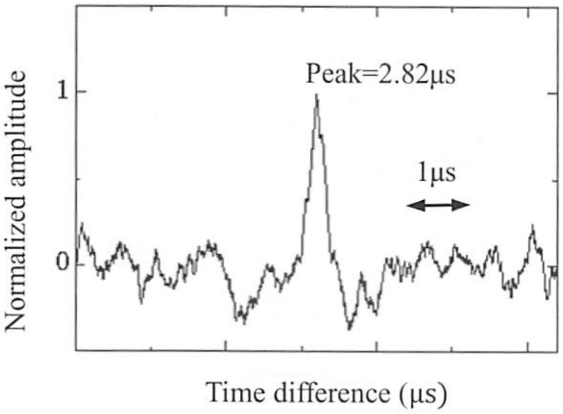

Fig. 7 Cross-correlation of the electrical signal and the vibration velocity shown in Fig. 6.

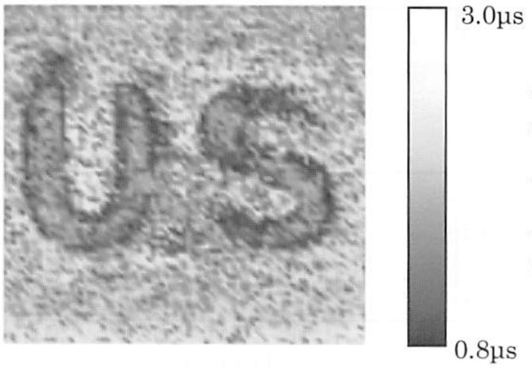

Fig. 8 Imaging results for silicone rubber using the delay time of the vibration velocity.

thickness measurements can also be expected to be performed on high attenuation samples using this system because the peak position of the cross-correlation, which corresponds to the propagation time of the ultrasonic wave, is clear under low S/N conditions. In this case, ultrasonic velocity v in sample can be calculated as,

$$\begin{aligned} v &= \frac{h}{\Delta t_m - \Delta t_s} \\ &= \frac{2\ \mathrm{mm}}{(2.82-0.74)\mu\mathrm{s}} \\ &= 865\ (\mathrm{m/s}). \end{aligned} \tag{1}$$

This value is in good agreement with the value of our previous paper5). Therefore, this method can be addressed as the quantitative measurement for the acoustic thin materials as well as the imaging.

The spatial resolution of the method is thought to be dependent on the laser beam spot size, and we intend to examine this aspect of the process in future work through more detailed experiments.

4. Conclusion

In this paper, a refined imaging method and system have been developed based on the vibration velocities on the surfaces of an ultrasonic transducer and the sample under test. In this method, a surface vibration velocity with the same amplitude and phase throughout the vibrating surface (USV) was successfully used with a constant-voltage driving source for the piezoelectric transducer. This made it possible to image the sample by detection of its vibration velocity, and the proposed system is also capable of imaging differences in the thickness or the velocity of sound under low S/N conditions. Use of hardware for the correlation process will be essential to reduce the time to obtain the image. The method is expected to form a new field of study in ultrasound imaging. The application of this method to various sample shapes and materials will be attempted in our future work.

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References

1) L. Kessler, "*Acoustic microscopy*, Nondestructive Evaluation and Quality Control Metal Handbook," ASM International, Materials Park, Ohio, pp. 5-15 (1989) 5.

2) K. Imano and H. Sato, "A New Ultrasonic Imaging Method in Air Using Vibrational Velocity at an Object," J. Soc. Mater. Eng. Resour. Jpn., **25** (1-2), pp. 13-19 (2013) [in Japanese].

3) M. Sato and Y. Yoshida, "Transient behavior of piezoelectric transducers driven by short pulse voltage," J. Acoust. Soc. Jpn., **53**, pp. 857-863 (1997) [in Japanese].

4) K. Imano, Y. Yoshida, and D. Okuyama, "Observation of the sound field in transient radiation from a concave piston source using time-transition pattern," J. Acoustic. Soc. Jpn., **E12**, pp. 233-235 (1991).

5) K. Saito and K. Imano, "Experimental Study on Intermediate Layer Made of (0-3) Composite Materials for Use in Air-Coupled Ultrasonic Transducers," Jpn. J. Appl. Phys., **46**, pp. 4479-4482 (2007).

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