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Estimation of Scattered Ultrasound Using Waveguides
導波管を用いた超音波散乱量の推定

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1. Principle of the Method

In studying inhomogeneous media consisting of two components or more, for instance porous materials such as bones or granular materials such as soil, scattering of ultrasound can be an important measure to identify their structures.[1-3) **Fig. 1** shows the most basic configuration for forward-scattering experiments, in which ultrasound is radiated towards the sample and the transmitted waves are detected by a receiver. The effect of scattering is usually evaluated from the spatial or angular dependence of the transmitted wave's amplitude, which can be measured by varying the position of the receiver. Although this method can be directly compared with scattering theories, it sometimes requires a large measurement region and a long measurement time, which are inconvenient if one aims to apply it to commercial instruments such as bone densitometers.

Fig. 2 shows the configuration of the measurement system we propose. In this method, transmitted waves from the sample are collected by a waveguide (any tubular object that can carry waves in its inside). The receiver is placed near at the other end of the waveguide. Transmitted waves from an inhomogeneous media contain scattered waves that are emitted into a certain solid angle that is determined by the relative size of the scatterer to the ultrasonic wavelength. The propagation time (time of flight) of the waves inside the waveguide is different by the angle of the incidence into the waveguide. The component that propagates parallel to the axis of the waveguide has the shortest propagation time, whereas obliquely incident components have longer ones. Therefore, if the ultrasound is emitted as a pulse or a tone-burst wave-packet, the received signal would have a different temporal shape compared with the initial signal: some "retarded" components are expected to emerge after the main part of the signal.

Since this method is equivalent to measure a superposition of the signals at various positions in Fig. 1, it does not provide precise data comparable to theories, but is rather appropriate for a rough estimation of the total amount of scattering in a downsized apparatus.

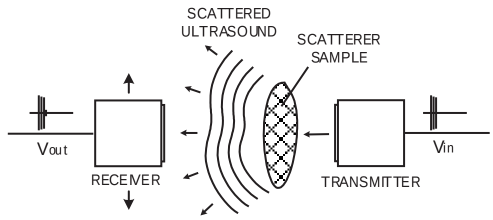

Fig. 1 Conventional method.

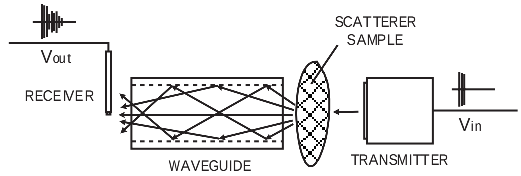

Fig. 2 Proposed method using a waveguide.

2. Experiment

Experiments were performed under the following conditions. Ultrasound was emitted at 1.4 and 2.4 MHz from a flat circular (12 mmϕ) transducer. Incident wave was a tone-burst with 10 μs duration, not precisely rectified but had a slowly rising forefront owing to the use of a power amplifier (500 W). The waveguide was a 60 mm-long aluminum pipe having a square cross section (inner size: 16× 16 mm). A small hydrophone (Toray, active area: 0.5 mm) was used as a receiver. The scatterer sample was a bovine cancellous bone with a thickness of approximately 7 mm. The size of its pores ranged approximately from 0.6 to 1.5 mm, whereas the thickness of the trabeculae ranged 0.15 to 0.4 mm. Marrow was removed beforehand and the experiment was done in a water-filled state.

Fig. 3 shows the experimental results at 1.4 MHz. Fig. 3(a) shows the received signal in the configuration of Fig. 1, where the sample-receiver distance was set to 25 mm. Fig. 3(b) and (c) show signals in the configuration of Fig. 2. In Fig. 3(b), retarded components are observed after the main part of the tone-burst signal, which presumably are the scattered (obliquely incident) components. The signal in Fig. 3(c) was obtained when the receiver was placed at a different vertical position, the rest conditions being unchanged from those of Fig. 3(b).

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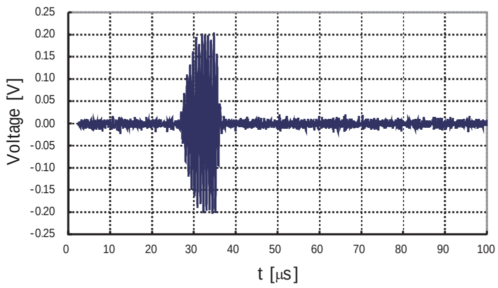
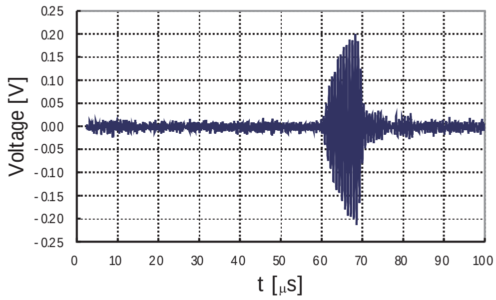
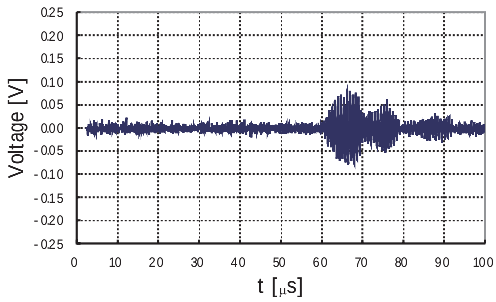


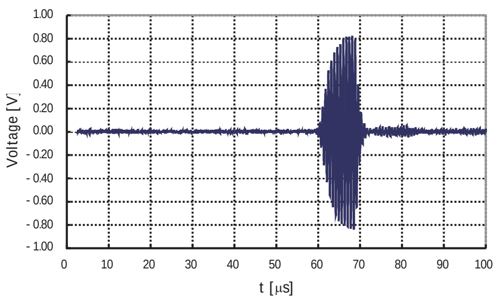
(a) signal in the configuration of Fig. 1



(b) signal in the configuration of Fig. 2
(with scatterer and waveguide)



(c) signal in the configuration of Fig. 2
(with scatterer and waveguide, received at a different vertical position)



(d) signal in the configuration of Fig. 2
(scatterer removed)

Fig. 3 Received ultrasonic signals at 1.4 MHz.

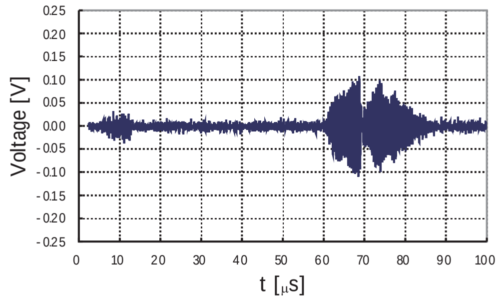


Fig. 4 Received ultrasonic signal at 2.4 MHz (with scatterer and waveguide).

As is shown, the ratio of the retarded components with respect to the main part depended on the vertical position of the receiver. Fig. 3(d) shows a signal when only the scatterer (bovine bone) was removed from the setup. Small-amplitude retarded components were observed, which are presumably due to the reflection between the transducer and the edge of the waveguide. **Fig. 4** shows a result at 2.4 MHz with the same scatterer and the waveguide, in which the scattered (retarded) component became relatively larger. The ratio of the retarded component to the main part also varied when the receiver was moved vertically.

3. Discussions and Summary

In the experiment, a small-sized receiver was used to decrease the phase-cancellation effect in detecting scattered waves the wavefront of which are usually bent and unknown. This provided a high sensitivity for scattered waves relative to the plane transmitted waves, but also caused a high dependence of the signal's shape on the receiver's position, as shown in Fig. 3(b) and (c).

In summary, it was confirmed that the scattered waves could be detected as temporally retarded components, and their amplitudes increased for a higher frequency. However, it was also observed that the temporal shapes of the received signals were considerably different by the position of the receiver. To establish a quantitative standard to connect the detected data to the scatterer's parameter, it is necessary to improve the method of detection or to add some signal processing.

References

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