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Proceedings of Symposium on Ultrasonic Electronics, Vol. 33 (2012) pp. 395-396
13-15 November, 2012

Measurement of shear wave displacement in tissues using elasticity phantom
生体疑似ファントムを用いた横波変位量計測の精度検討

Hirofumi Sasaki[1†], Shinnosuke Hirata[1], and Hiroyuki Hachiya[1] ([1]Tokyo Inst. of Tech.)
佐々木日史 [1†]，平田慎之介 [1]，蜂屋弘之 [1] ([1]東工大)

1. Introduction

It is known that the shear modulus of the fibrotic liver tissues becomes larger than that of the normal tissues. Many approaches to evaluate the degeneration degree of liver by generating shear wave in tissues have been proposed. However, the method using acoustic radiation force to generate shear wave has potential to produce bio-effects on human tissues. So it is desired to improve measurement sensitivity of the shear wave. In this study, we generated shear wave in the phantom containing the spheres whose elasticity is different from background medium. Then we measured shear wave displacement by the ultrasound pulse wave and evaluated its measurement accuracy.

2. Measurement method of shear wave displacement

We generated shear wave in the phantom by the acoustic radiation force of focused ultrasound generated by concave transducer. Used phantom is CIRS MODEL049. As shown in **Fig. 1**, it contains four spheres whose shear modulus is different from background. The frequency of the ultrasound which is used to make B-mode images is 3.75 MHz. The echo intensity of the spheres in B-mode images is same as that of background. The distance between the top face of the phantom and the concave transducer is equal to the focal length of the transducer. Focused ultrasound used to generate the acoustic radiation force is a burst wave of 2.3 MHz sine-wave signal and its duration is about 20 ms. **Fig. 3** shows generated ultrasound waveform and its negative peak pressure is -1.12 MPa.

In this study, we calculated the shear wave displacement by phase difference of the echo signals. First, we demodulated the echo signals of the pulse wave by quadrature detection and got its initial phase $\phi_i(d)$ where d is the depth and i is the frame number of the B-mode images. Next, we calculated phase difference between the demodulated echo signals of successive B-mode images and it is expressed as $\Delta\phi_i(d) = \phi_{i+1}(d) - \phi_i(d)$. Then we converted it to the axial displacement Δx from the equation

$$\Delta x_i(d) = \frac{\lambda \Delta\phi_i(d)}{4\pi}, \quad (2)$$

where λ is the wave length of the pulse wave in the water. Positive Δx means downward displacement of shear wave and negative Δx means upward displacement.

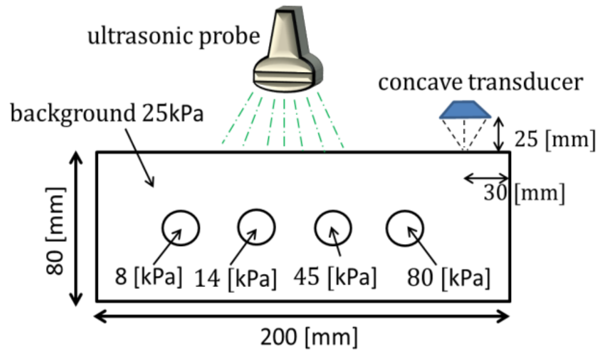


Fig. 1 Experiment configuration to generate and measure shear wave displacement

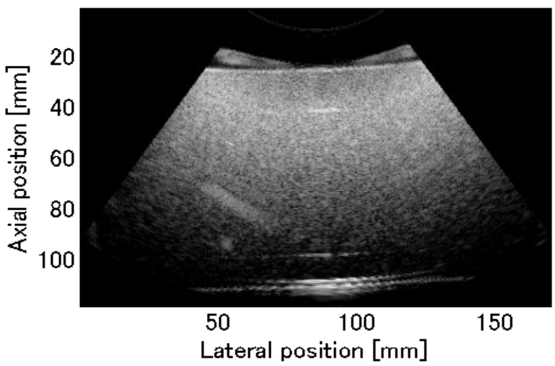


Fig. 2 B-mode image of the used phantom

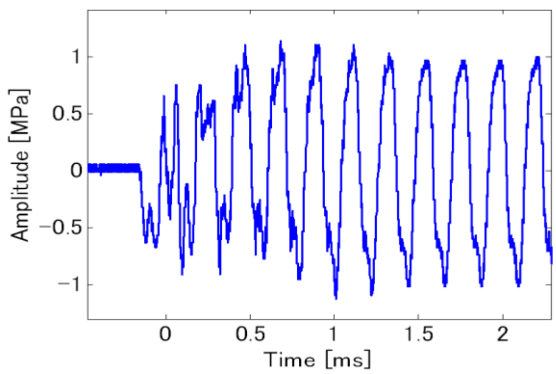
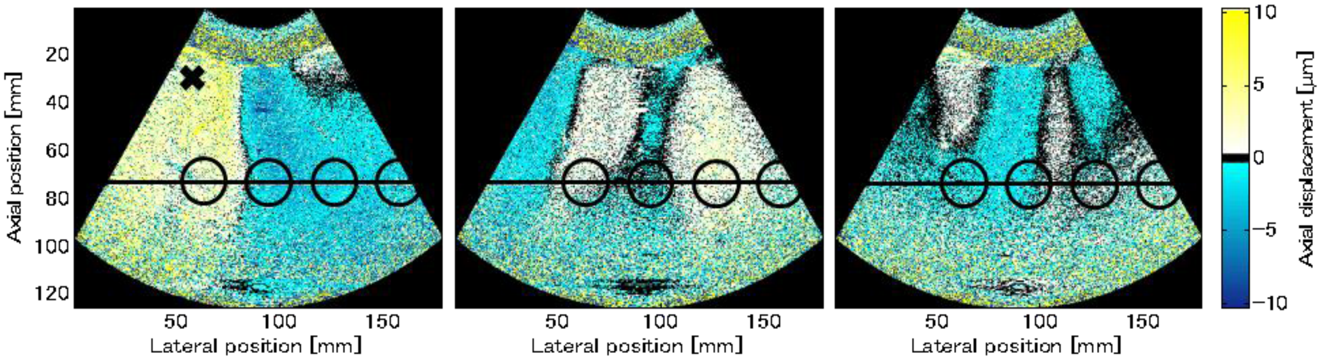


Fig. 3 Time waveform of intense focused ultrasound

E-mail address: sasaki@us.ctrl.titech.ac.jp



(a) t=0.16 s (b) t=0.20 s (c) t=0.24 s

Fig. 4 2D-plot of the measured axial displacement

3. Results and discussion

Fig. 4 shows 2-D plot of the axial displacement. Time interval of adjacent plots is 0.4 s and t means elapsed time from the beginning of measurement. Shear wave is generated at time between 0.10 s and 0.12 s. Circles in the figures show the positions of the spheres and their elasticity are 8 kPa, 14 kPa, 45 kPa, 80 kPa from left. The maximum axial displacement is about 10 μm and it is about 1/20 of the ultrasound wave length. Because the brightness of the water in B-mode images is very small and the displacement cannot be measured properly in the region of water, we adjusted the scale of the colorbar not to be displayed the displacement information in that region. In **Fig. 4**(a), we can observe the wavefront distortion in the vicinity of the spheres and it is considered to be generated by difference of the elasticity. **Fig. 5** shows the axial displacement at the depth 72 mm as a function of lateral position, which is shown in the **Fig. 4** by the black line. We can observe spatial frequency of shear wave is very different between two frames because of the effect of shear wave reflection at the boundary of the phantom. **Fig. 6** shows the axial displacement at the point of cross mark in the **Fig. 4**(a) (axial position=28mm, lateral position=55 mm) as a function of time. This indicates shear wave amplitude becomes peak immediately after vibration and it attenuates to halves after 200 ms.

From these results, we discovered shear wave reflects at the phantom circuit and it greatly effects on the results of the measurement after about 200 ms. Furthermore, because amplitude of shear wave attenuates suddenly, it is difficult to measure shear wave displacement properly after about 500 ms.

References

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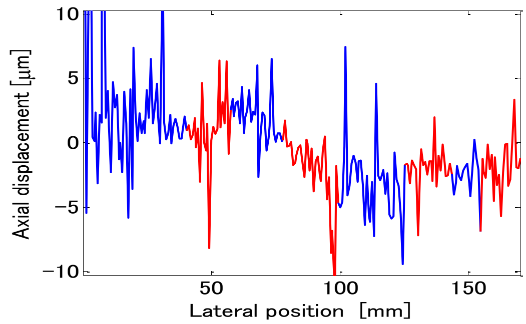
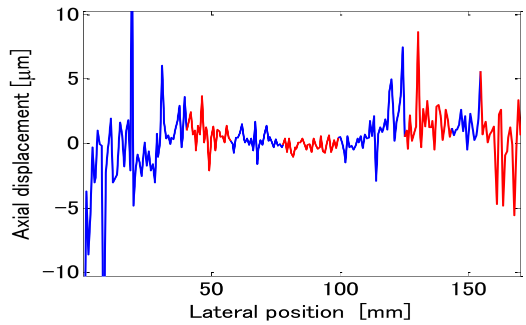
4. Conclusion

We measured shear wave displacement less than 10 μm and observed the distortion of shear wave front generated by the difference of elasticity. Moreover, we figured out the effect of the reflected shear wave and the time change of the shear wave amplitude. For the future, we will consider measurement accuracy of elasticity by measuring immediate shear wave after vibration in detail.



(b) t=0.16 s



(a) t=0.20 s

Fig. 5 Axial displacement as a function of lateral position

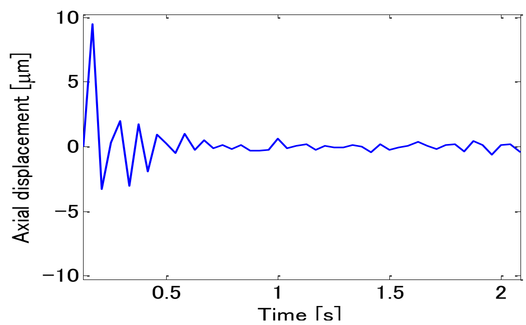


Fig. 6 Axial displacement as a function of time