A Study for Real-time B-mode Imaging using 100-MHz-Range Ultrasound through a Fused Quartz Fiber

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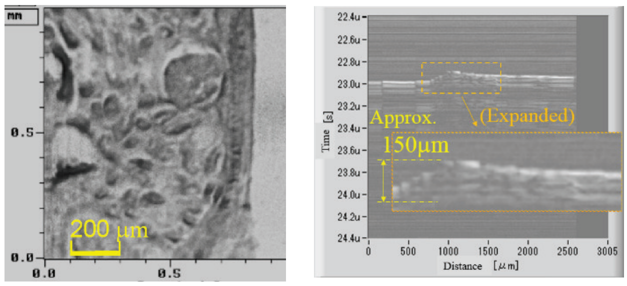
***Abstract*— We have studied C-mode and B-mode imaging using high-frequency ultrasonic waves through a thin fiber for direct observation of the microscopic image of tissue. We reported previously that the C-mode images of the tissue on the glass and B-mode image of animal bone placed in water were obtained using a fused quartz fiber as the needle-type ultrasound probe. In this paper, we propose a method for the real-time B-mode imaging, and show experimental results.**

Keywords-component; high-frequency ultrasonic wave, microscopic image, quartz fiber, real-time B-mode image, needle-type ultrasonic probe

I. INTRODUTION

Tissue diagnosis in the current pathological examination takes time because it requires a tissue sample obtained by the biopsy and the observation using an optical microscope, and gives burden on the patient. The main objective of the study is to enable an operator to observe directly microscopic images of the tissue without taking out the tissue sample from the patient. To achieve the objective, we are developing a needle-type ultrasonic prove that uses a thin fiber as an ultrasonic probe [1], [2]. Since the diameter of the probe is so small that it can be inserted into body tissue without giving a severe burden on the patient and still retain non-invasiveness.

We reported that high-frequency ultrasonic waves (70 - 175MHz) were transmitted and propagated approximately 1.6mm in the acoustic coupling medium, and a C-mode image of a coin placed in water was obtained using a tapered fused quartz fiber as the probe [3]. Moreover, the lateral resolution of the image was improved by using the focused ultrasonic-beam, and the fine C-mode image of tissue sample (kidney) as shown in Fig.1-(a) was obtained [4]. In the previous study, a B-mode image of tissue sample (body of vertebra of pig) as shown in Fig.1-(b) was obtained [5]. In this study, we proposed a method to realize the real-time B-mode imaging without increasing the diameter of the probe as shown in Fig.-2. As the results of the experiment, the static (not real-time) B-mode image was obtained as the first stage of the study.



(a) C-mode image of kidney (b) B-mode image of animal bone

Fig. 1. Microscopic itissue mages obtained in previous experiments

II. METHOD OF REAL-TIME B-MODE IMAGING

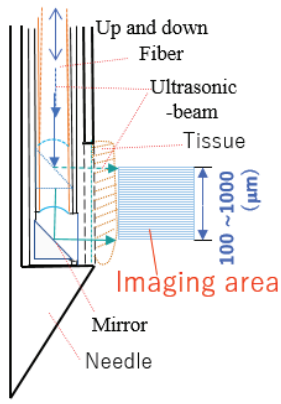


Fig. 2. A method to obtain real-time B-mode image

As shown in Fig.2, the direction of the focused ultrasonic-beam radiated from the fiber is reflected at right angle by the mirror. And the real-time B-mode image can be obtained by moving quickly the fiber with mirror up and down.

III. EXPERMENTS

A. Processing of Fiber

As shown in Fig. 3, one side of the fiber has a flat plane, and the other side has a concave-surface to obtain the focused ultrasonic-beam. The concave-surface side of the fiber was processed to obtain the longer focal length compared to the one (approx. 0.8 mm) of the fiber used in the previous experiment.

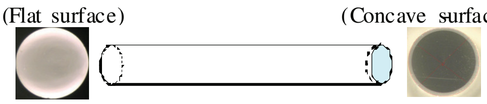


Fig. 3. Processed end-surfaces of fiber

After processing the fiber, we measured the profiles of the concave-surface of the fiber using an Optical Profiler Wyko NT3300 (Veeco Instruments Inc.). The results were shown in Fig. 4.

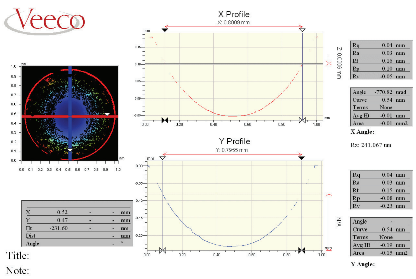


Fig. 4. Profiles of concave-surface of fiber

B. Experimental System

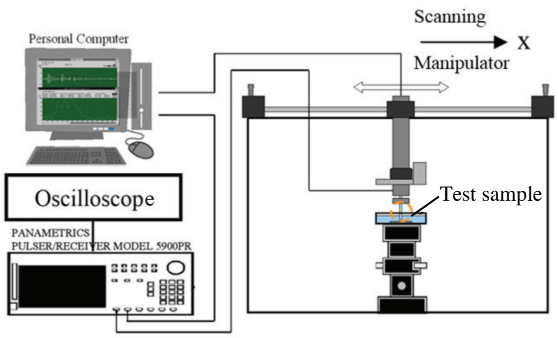


Fig. 5. Schematic of measurement and imaging system

As shown in Fig. 5, the system consists of a pulser/receiver (Panametrics model 5900PR), a 220 MHz transducer (Panametrics model V2113) for transmitting and receiving, Personal Computer including a NI LabVIEW, a fused quartz fiber, a test sample (or reflector) and an oscilloscope (LeCroy 64MXs). The ultrasonic pulse (approximately 50 Vp-p amplitude) with a wide frequency-band width (95~278 MHz) was transmitted into the fiber. The transducer and the fiber were assembled together to maximize the amplitude of the reflected wave from the test sample.

C. Reflection of Ultrasonic-Beam at Right Angle

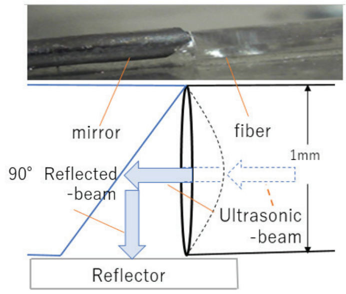


Fig. 6. Reflection method of ultrasonic-beam at right angle

The ultrasonic-beam radiated from the fiber is reflected at right angle by the mirror. Then the beam strike against the reflector and come back to the fiber through the same way.

IV. MEASUREMENTS

A. Measurement of Focal Length

In order to determine the focal length, we measured the amplitude of the echo from the reflector (stainless steel board) in water as a function of the distance from the reflector by moving the transducer (or reflector) to Z direction.

1) Measurement of focal length for straight ultrasonic-beam

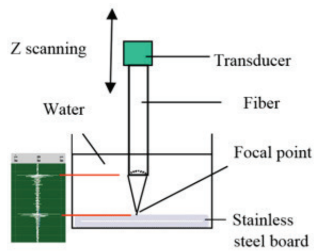


Fig. 7. Measurement system of focal length for straigh-beam

As shown in Fig. 7, the measurement of the focal length was performed by moving the transducer to Z direction.

2) Measurement for 90° reflected ultrasonic-beam

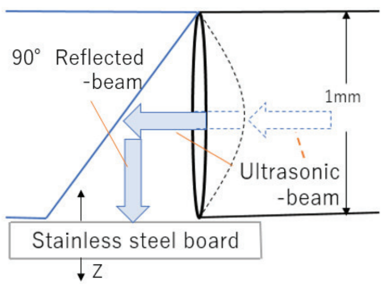


Fig. 8. Measurement system of focal length for 90° reflected-beam

As shown in Fig. 8, the measurement of the focal length was performed by moving the stainless steel board to Z direction.

B. Measurement of Spatial Resolution in B-mode Image

By performing the B-mode image of a “13 µm (diameter) stainless steel mesh”, we estimated the spatial resolution

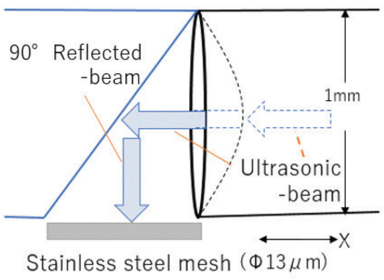


Fig. 9. Measurement system of spatial resolution

The mesh was moved toward the X direction as shown in Fig. 9. The minimum interval for the movement of the mesh (that is the scanning-interval of the ultrasonic-beam) was 1 µm

C. Measurement of Ultrasonic-Beam Profile

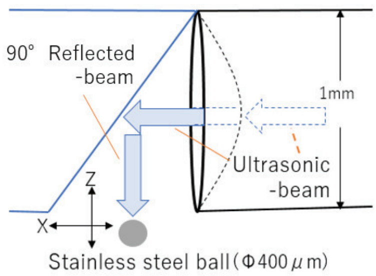


Fig. 10. Measurement system of ultrasonic-beam profile

The stainless steel ball with 400µm diameter was moved toward X and Z direction as shown in Fig. 10. The scanning-interval was 1 µm in each direction.

D. B-Mode Imaging of Tissue Sample

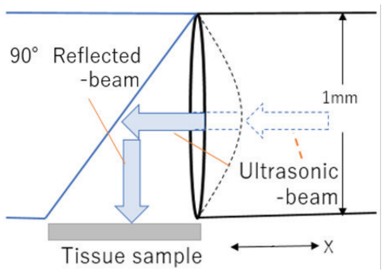


Fig. 11. B-mode imaging system

As shown in Fig.11, B-mode imaging of the tissue sample was performed by moving the sample to X-direction. The minimum scanning-interval of the ultrasonic-beam was 5 µm. As a sample tissue, an animal bone (body of vertebra of pig) was used.

V. RESULTS

A. Focal Length of Ultrasonic-Beam

1) Focal Length of straight ultrasonic-beam

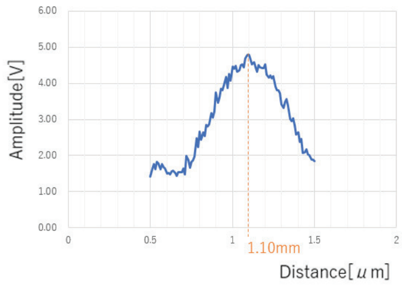


Fig. 12. Focal length of straight ultrasonic-beam

As shown in Fig. 12, focal length of the straight ultrasonic-beam was approximately 1.10 mm from the end of the fiber.

2) Focal Length of 90° reflected ultrasonic-beam

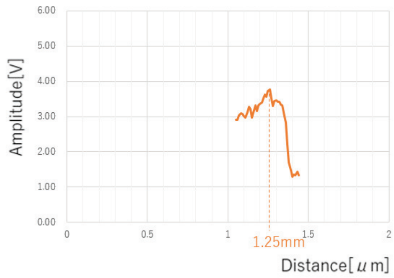


Fig. 13. Focal length of 90° reflected ultrasonic-beam

The focal length of the reflected ultrasonic-beam was approximately 1.25 mm from the end of the fiber as shown in Fig. 13.

B. Beam Profile of Reflected Ultrasonic-beam

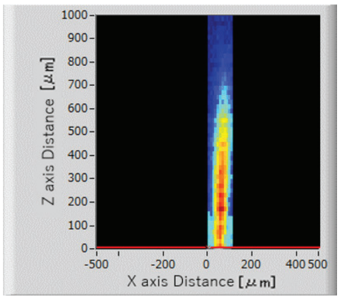


Fig. 14. Profile of reflected ultrasonic-beam

The profile of the reflected ultrasonic-beam was obtained as shown in Fig. 14.

C. Spatial Resolution in B-Mode Image

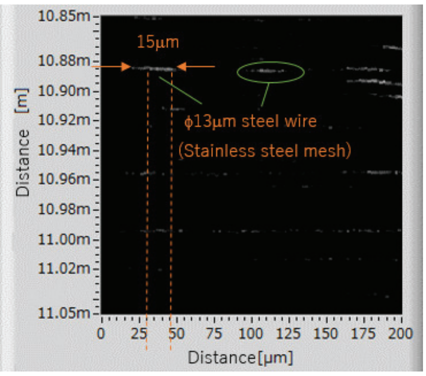
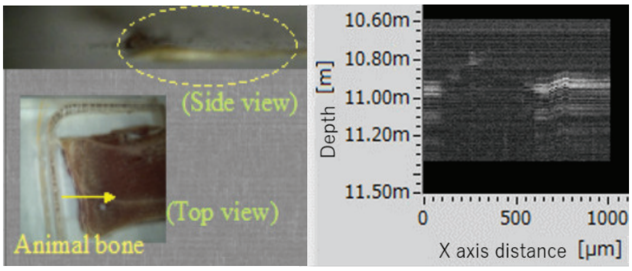


Fig. 15. B-mode image of stainless steel mesh

B-mode image of the stainless steel mesh with 13 μm wires in diameter was obtained as shown in Fig. 15. The echoes from the wires could be seen on the B-mode image.

D. B-mode Image of Tissue sample



(Photo.) B-mode image

Fig. 16. B-mode image of animal bone

The B-mode image of the animal bone (body of vertebra of pig) was obtained as shown in Fig. 16.

VI. DICUSSION

By processing the concave surface of the fiber, the longer focal length (approx. 1.10 mm) of the ultrasonic-beam radiated from the end of the fiber was obtained (Fig. 12) compared to the one (approx. 0.8 mm) used in the previous experiment. As shown in Fig. 13, it was recognized that the ultrasonic-beam radiated from the end of the fiber was reflected at right angle by the mirror. And the focal length of the beam was extended to approx. 1.25 mm compared to the one (approx. 1.10 mm) of the strait-beam. However, the maximum amplitude of the ultrasonic-beam decreased to approx. 3.7 V_{P-P} compared to the one (approx. 4.8 V_{P-P}) of the strait-beam as shown in Fig.-12 and 13. It was supposed that the extension of the focal length and decreasing of the amplitude depended on the slant of the mirror. As shown in Fig. 15, the lateral and the range resolution in the B-mode image was approximately 15 μm and up to 13 μm, respectively. The B-mode image of the tissue sample (body of vertebra) was obtained, but the quality was poor. The one of the reasons of it was the low sensitivity of ultrasonic wave radiated from the fiber.

VII. CONCLUTION

It was successful to reflect the ultrasonic-beam at right angle by the mirror. As shown in Fig. 15, the spatial resolution of the B-mode image seems to be approximately 15 μm. The B-mode image of the tissue sample (body of vertebra) was obtained, but the quality was poor. Because the sensitivity of the ultrasonic wave radiated from the fiber was low, as shown in Fig. 12. It should be improved in the next task. As the results of the experiments, we expect that the microscopic image of the tissue can be seen directly in real-time by improving the sensitivity of the ultrasonic wave radiated from the fiber.

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