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

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***Abstract*— We have studied transmission methods of high-frequency ultrasonic waves through a thin fiber for direct observation of the microscopic image of the tissue. We reported previously that the C-mode images of the tissue on the glass placed in water were obtained by penetration method using a fused quartz fiber as the probe. In this paper, we describe that the B-mode image of a sample tissue in water was obtained by reflection method using the focused ultrasonic beam.**

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

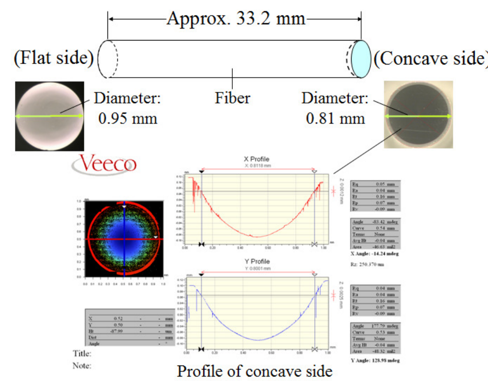
I. INTRODUCTION

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 a 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 [1], [2] as an ultrasonic probe [3]. 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.

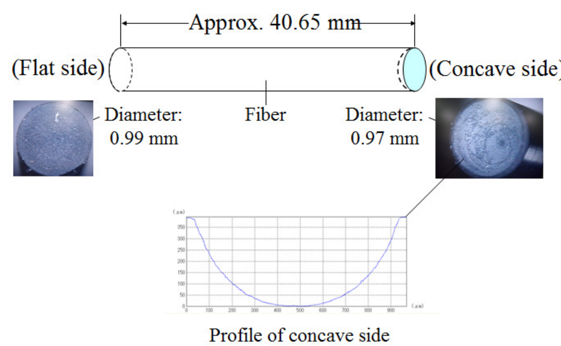
We reported that high-frequency ultrasonic waves (70 - 175MHz) were transmitted and propagated approximately 1.6mm in the acoustic coupling medium, and a C-mode image of a coin placed in water was obtained, using a tapered fused quartz fiber as the probe [4]. Moreover, by improving the lateral resolution of an ultrasound beam, and fine C-mode images of an artificial bone and an animal bone placed in water were obtained using a reflection method. In the previous study, C-mode images of tissue samples (mucosal layer of the stomach and kidney with approximately 10 micrometer thickness) on a glass plate in water were obtained in a penetration method. In this study, we describe that the sensitivity of the ultrasonic wave radiated from the transducer increased by improving the focused ultrasonic beam, the B-mode image of a tissue sample (animal bone) in water was obtained by a reflection method.

II. EXPERIMENT

A. Improvement of focused ultrasonic beam



(a) Fiber used in previous experiments



(b) Fiber used in this experiment

Fig. 1 Profile processed cocave-surface and focusing characteristics of fiber

Figure 1 (a) and (b) show the profile of the concave surfaces of the fiber previously used and that used in this experiment respectively.

B. Experimental system

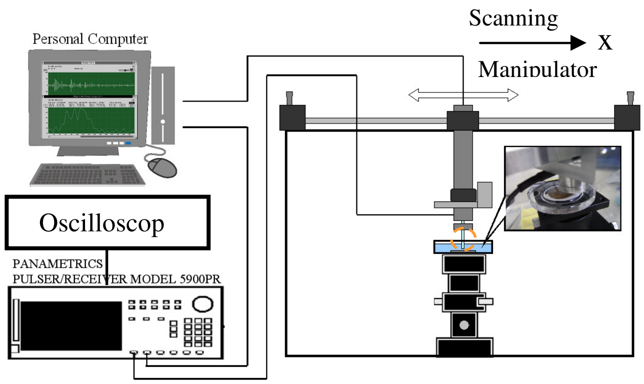


Fig. 2 Schematic of measurement and B-mode imaging system

As shown in Fig. 2, 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 tissue sample (body of vertebra of pig) and an oscilloscope (LeCroy 64MXs). The transducer and the fiber were assembled together to maximize the amplitude of the reflected wave from the concave side of the fiber. A tissue sample or a reflector was placed at the focal point of the fiber that has a concave surface. The ultrasonic pulse (approximately 50 Vp-p amplitude) with a wide frequency-band width (95~278 MHz) was transmitted into the fiber.

C. Measurements

1) Measurement for detectable distance of echo from the reflector and the focal point of ultrasonic beam

In order to determine the focal point and the detectable range of the system, we measured the amplitude of the echoes from the reflector (stainless steel board) in water as a function of the distance from the reflector by moving the transducer to Z direction as shown in Fig. 2.

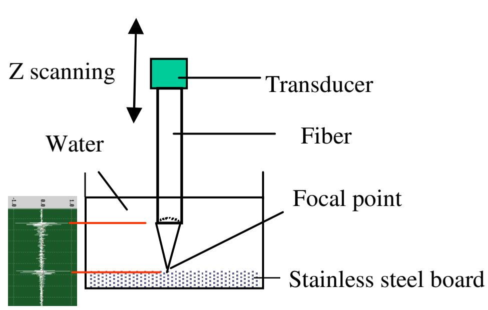


Fig. 2 Measurement system of detectable distance of echo from the reflector and focal point of ultrasound beam

2) Measurement for detectable size of reflector and beam profile

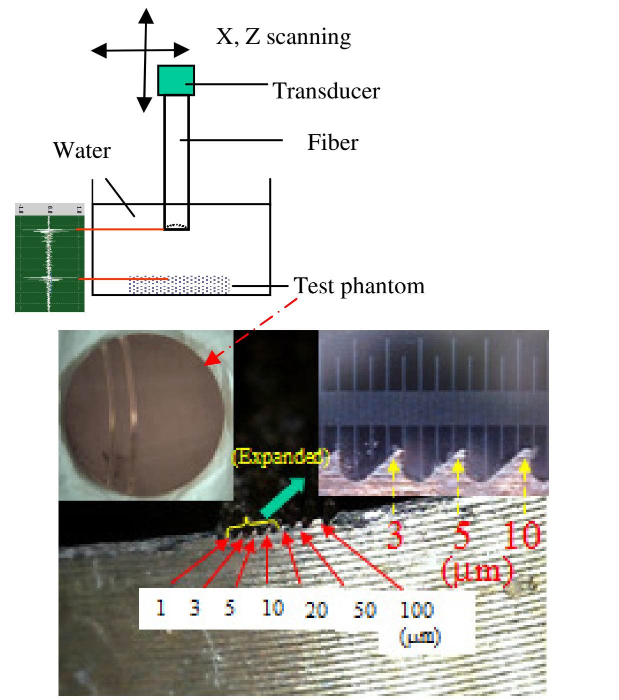


Fig. 4 Measurement system of detectable size of reflector and beam profile

We tested to detect the echoes from the targets with extremely small size (1, 3, 5, 10µm, and so on), as shown in Fig. 4. After detecting the echoes from the targets, the transducer was moved toward X and Z directions continuously in order to obtain the transmitted beam profiles.

3) Measurement for spacial resolution of ultrasonic beam using stainless steel mesh

In order to estimate the special resolution, we performed the B-mode imaging of a "13 µm (diameter) stainless steel mesh" using a scanning system as shown in Figs. 2 and 5.

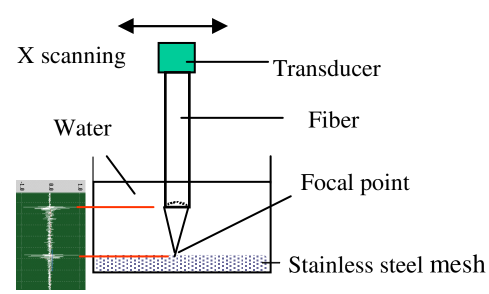


Fig. 5 Measurement system of special resolution using a "13 µm (diameter) stainless steel mesh"

The transducer was moved toward the X direction over the mesh.

The minimum interval for the movement of the transducer (that is the scanning-interval of the ultrasonic beam) was 1 µm.

D. B-mode imaging of tissue sample

B-mode imaging of the tissue sample was performed using the experimental system as shown in Fig. 2. The focal point of ultrasonic beam was set on the surface of the sample in water. In the B-mode imaging, the minimum scanning-interval of the ultrasonic beam was 5 µm, and the minimum scanning widths in X direction was 1 mm. As a sample tissue, an animal bone (body of vertebra of pig) was used.

III. RESULTS

A. Resuts of measurements

1) Measurement for detectable distance of echo from reflector and focal point of ultrasonic beam

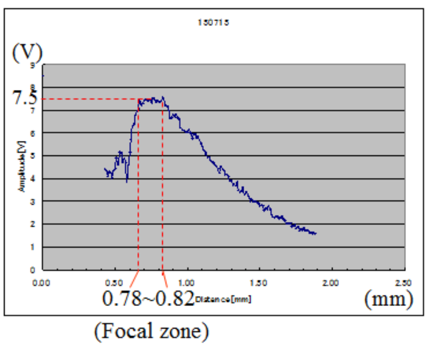


Fig. 5 Detectable distance of echo from reflector and focal point of ultrasound beam

As shown in Fig. 5, the detectable range of an echo and the focal zone was approximately 1.9 mm and 0.78 mm from the end of the fiber, respectively.

2) Measurement for detectable size of reflector and the beam profile using test phantom

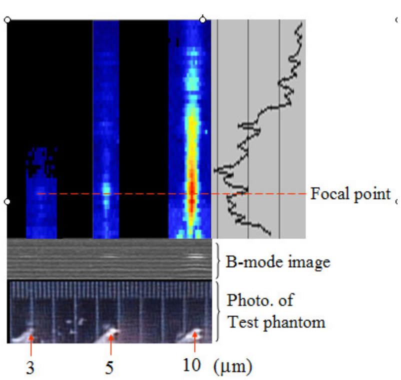


Fig. 6 Detectable size of test phantom and beam profile

As shown in Fig. 6, the echoes from the reflectors (3, 5 and 10 µm size) of the test phantom and the beam profile were obtained.

3) Measurement for spacial resolution of ultrasound beam using stainles steel mesh

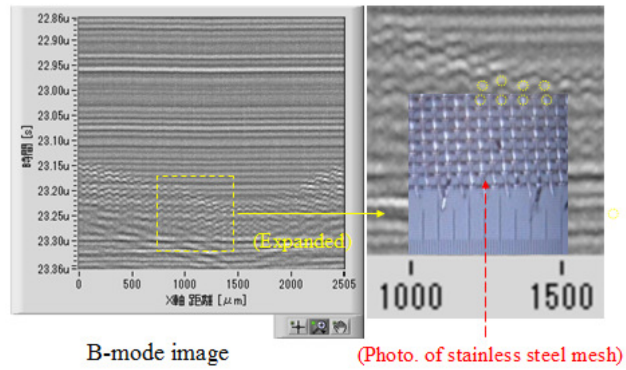


Fig. 7 B-mode image of the stainless steel mesh

B-mode image of the stainless steel mesh with 13 µm wire in diameter was obtained as shown in Fig. 7. The echoes from the 13 µm wires could be seen on the B-mode image.

B. B-mode imaging of tissue sample

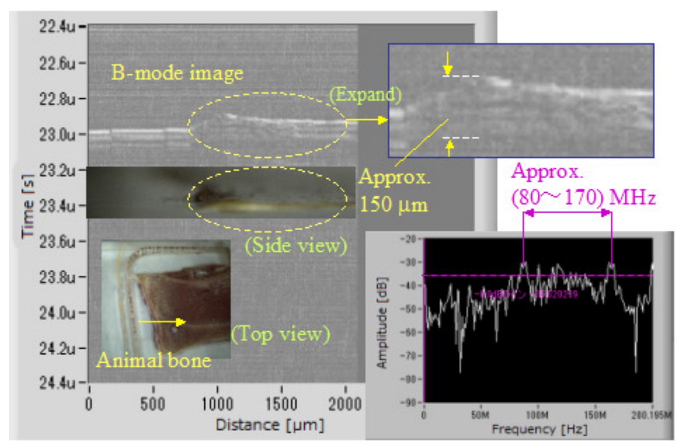


Fig. 8 B-mode image of animal bone and frequency characteristic of reflected wave

Figure 8 shows the B-mode image of the animal bone (body of vertebra of pig). The frequency band of the image was approximately 80-170 MHz. The propagation distance of the ultrasonic wave in the sample bone was approximately 150 µm due to the attenuation of ultrasonic wave.

IV. DICUSSION

Sensitivity of the ultrasonic wave radiated from the fiber was improved approximately 3 times compared to the previous one. It seems that the main reason of the improvement was due to processing of the concave surface of the fiber, and the detectable range of the echo from the reflector increased. Moreover, as the focal zone became wide, it becomes an advantage for obtaining widely clear B-mode image. The length of the focal zone can be seen in the beam profile of Fig. 6. Detecting the extremely small size (3 μm) reflector means improvement of lateral resolution compared to the previous one. The B-mode image of the stainless steel mesh with 13 μm wire in diameter was obtained, but it is not so clear. The one of the reasons of it was the difficulty of setting the extremely small and thin mesh (knit with 13 μm wires) in water. As the results of the measurements (Fig. 6 and 7), it is considered that the spatial resolution of the image was approximately up to 13 μm. In the B-mode imaging of a tissue sample (animal bone), the measured propagation distance of the ultrasonic wave in the animal bone was approximately 150 μm due to the attenuation of an ultrasonic wave. The frequency band of the image was approximately 80-170 MHz.

V. CONCLUSION

B-mode image of the tissue sample (body of vertebra of pig) was obtained in the reflection method. As an image of the stainless steel mesh (knit with 13 μm wires) and small reflectors (3-5 μm size) were also obtained, it was shown that the special resolution of the image was approximately up to 13 μm. The frequency characteristic of echoes from tissue samples have high frequency spectrum, approximately 80-170 MHz.

As the results of the experiments, we expect that the microscopic image of the tissue can be seen directly in real time.

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