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Relationship between MEMS Mirror Angle and Beam Characteristics in High-Speed Scanning Ultrasound Microscopy

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1. Introduction

Ultrasound microscopy has pioneered the biomechanical diagnosis of cancer and atherosclerosis because it can assess the three-dimensional distribution of mechanical properties such as elasticity and viscocity without histochemical staining[1)]. However, real-time imaging of ultrasound microscopy is challenging because the frame rate is limited by mechanical scanning of the transducer. By using the linear actuator stage, increase of the scanning speed is not easy as it often generates greater vibrations of the transducer and deteriorates the image quality. In the previous ultrasound microscopes, the imaging speed to obtain one image was several seconds to several minutes[2)]. To increase the frame rate with preserving the image quality, we are developing a new high-speed scanning ultrasound microscope using the MEMS mirror. Since the MEMS mirror can move faster than the linear scanner without causing any vibration of the transducer, it has a strong potential to improve the temporal resolution of ultrasound microscopes[3)]. In this study, the effect of the angle of the MEMS mirror on the acoustic beam characteristics was investigated for future development of MEMS-ultrasound microscope.

2. Materials and Methods

2.1 Control of MEMS mirror

This study used the commercial MEMS mirror unit (S12237-03P, Hamamatsu photonics) to change the acoustic pulse direction. **Fig. 1** shows the control sequence of a cycle of mirror movement. Div (Frequency division ratio) was determined by the following equation,

$$\mathrm{Div} = \frac{f_{\mathrm{clock}}}{f_{\mathrm{set}} \cdot N} - 1 \qquad (1)$$

where f_{set} represents the driving frequency, f_{clock} is the MEMS mirror driver's system clock of 100 MHz, and N represents the number of sampling points. Since the MEMS mirror movement was given as a sinusoidal function, the direction of the first half cycle of the motion was opposite to that of the second half cycle. To unify the scanning direction for the imaging, the internal trigger was used to transmit and receive acoustic pulses during only the first half of the period. PRF of the acoustic pulses and DAC update rate of the MEMS mirror were respectively configured so that acoustic transmission and receiving could complete before the MEMS mirror angle was changed to the next point. For each transmission, the received echo signal was recorded for 20 μs.

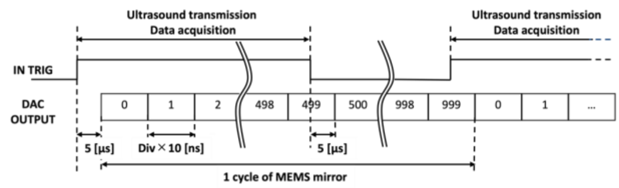

Fig.1 Synchronous Signal Timing Chart

2.2 Outline of the experimental system

Controlling the MEMS mirror and acoustic data acquisition was performed as follows. First, a personal computer sent the start command to the driver of the MEMS mirror, which instantly activated the internal trigger to a function generator (NF Corporation WF1944B). Next, once the function generator received the trigger, it output square pulses to control the timing of the acoustic transmissions. The timing control signal was received by a pulser-receiver (Honda Electronics Co., LTD.) equipped with a single element transducer with the central frequency of 20 MHz. After each transmission, the echo signal from the target was received by the same transducer and the pulser-receiver. Finally, the received signal was amplified by 50 dB and sent to an AD converter (SPECTRUM DN2.221-08) to record the data. Note that there should be nano-scale delay time for each activation of the triggers, but we assumed all the latency was negligible for this study.

2.3 Experiments

Using the experimental MEMS-ultrasound microscope, the basic experiments to assess the stability of the echo spectrum in the applied the

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MEMS mirror angles and the image quality using the setup shown in **Fig. 2**.

For the spectrum assessment, the echo signal from a metal plate placed at 7 mm in depth (the geometric focus of the transducer) in pure water was acquired. The MEMS mirror driving range was set to ±10 deg in X axis in Fig.2, and the driving frequency was 10 Hz. PRF of acoustic pulses was 10 kHz, and the echo data was recorded at the sampling rate of 156.25 MHz. For the evaluation, echo signals acquired at the MEMS mirror angles from 0 to 10 degrees by 1 degree step were extracted, and the spectrum of each echo signal was computed with Fast Fourier Transform (FFT). The spectrum curves were used to assess whether the mirror-angular dependency presents in the center frequency and the bandwidth of the echo signals.

In addition, the image quality of the proposed system was verified by the full width at half maximum (FWHM) of the cumulative distribution function (CDF). In this experiment, the MEMS mirror angle was set to 0 degree so that the acoustic beam direction was converted from Y axis to Z axis, which is the orthogonal to the surface of the metal plate placed in the water tank. Then, the metal plate was moved along the X direction using a linear stage so that the echo signals across the edge of the plate could be acquired. The edge spread function was calculated by plotting the maximum amplitude of each echo signal and fitting the points with the cumulative distribution function (CDF) of the normal distribution. Using the estimated parameters of the normal distribution, FWHM was calculated[3). As a comparison, the transducer was placed along the Z axis to emit pulses to the metal plate without using the MEMS mirror, and echo signals and FWHM were acquired using the same experiment steps. Finally, a B-mode image of the metal plate was generated using the proposed system to show its visualization capability.

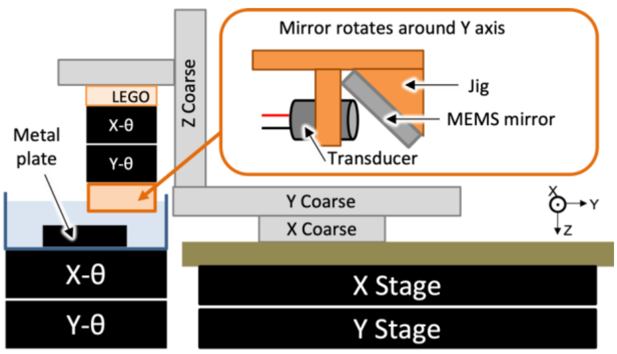

Fig. 2 Experimental system

3. Results and Discussion

First, from the spectrum assessment, the mean center frequency was found to be 14.30 ± 0.01 MHz. In addition, as shown in **Fig. 3(a)**, the spectrum curves of the echo signal taken at various MEMS mirror angles strongly correlated with each other, suggesting the characteristics of the echo signals did not change with the MEMS mirror angle.

Second, the result of CDF fitting using the echo data of the metal plate's edge is shown in **Fig. 3(b)**. FWHM from the echo data with the MEMS mirror was estimated to be 0.686 mm, which was comparable with 0.791 mm derived from the data acquired without the MEMS mirror. This observation suggested that the image resolution was almost the same regardless of the use of the MEMS mirror.

Finally, **Fig. 3(c)** shows the generated B-mode image. Although the out-of-frame signal from the MEMS mirror was involved in the image, the metal plate could be imaged, indicating that the proposed system could be used for B-mode images in the future studies.

4. Conclusion

In this study, a prototype of the MEMS-ultrasound microscope equipped with the MEMS mirror was developed and the echo signals were evaluated. The experiments showed that the MEMS mirror would not affect the spectrum and the beam shape of the acoustic beam, and hence it will be useful for improvement of the temporal resolution of the acoustic microscopes.

References

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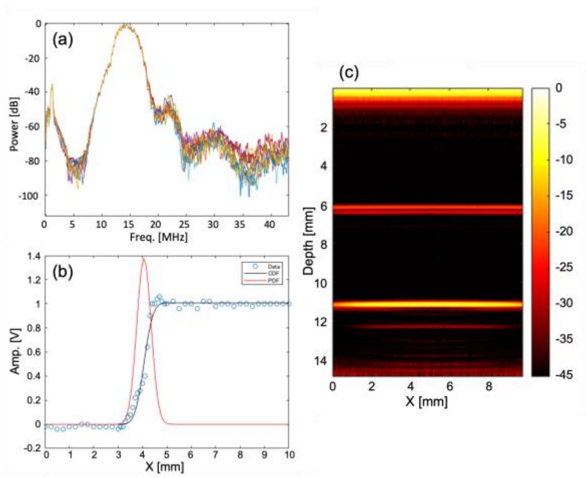

Fig. 3 (a) Spectrum of echo signals taken at mirror angles from 0–10 degrees, (b) CDF fitting with the MEMS mirror, (c) B-mode imaging of metal plate