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Axisymmetric Finite Element Simulation for High Intensity Ultrasound Source System using Acoustic Waveguides

音響導波路を用いた高強度超音波音源システムの開発を目的とした軸対称有限要素解析

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1. Introduction

In recent years in medical field, high intensity focused ultrasound has been used in many ways for cancer treatment including acoustic chemotherapy (sonodynamic therapy), for sonoporation to gene transfer, for ultrasonic elastography to image the hardness of soft tissues and organs by using acoustic radiation force impulse, and for harmonic imaging methods that utilize harmonics in diagnosis. In industrial field, high intensity ultrasound is also used for applications such as ultrasonic cleaners or ultrasonic dispersers.

The National Metrology Institute of Japan has been developed measurement standards for ultrasonic[1]. The hydrophone sensitivity calibration is performed by using the absolute calibration system with a polyethylene terephthalate (PET) membrane with a deposited Au film, a laser interferometer, and the comparative calibration system with a reference membrane type hydrophone. The acoustic pressure at the measurement position of the reference membrane type hydrophone should be known in order to calibrate the sensitivity of the reference membrane type hydrophone. Ultrasonic wave should be irradiated on the PET membrane with uniform intensity high acoustic pressure and plane wave by using reference transmitting ultrasonic transducer[2].

Therefore, it is necessary to develop an ultrasound source to transmit high intensity ultrasound pressure, and to calibrate a hydrophone for measuring high intensity acoustic field.

2. Ultrasound source system using acoustic waveguides

We propose an ultrasound source system for irradiation of the high acoustic intensity, by not only applying high voltage to the electrodes of the piezoelectric element, and for generating an acoustic beam by using acoustic waveguides and a concave type transducer.

Ultrasound focused waves are emitted from the concave type transducer surrounded by conical acoustic waveguide, focused to an end of the cylindrical acoustic waveguide, and irradiated from another end (transmitting aperture) by propagating through the cylindrical acoustic waveguide. The model of our proposed source system is shown in **Fig. 1**.

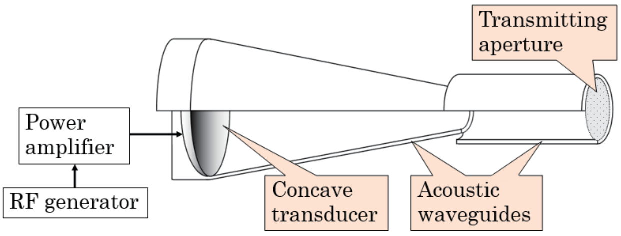

Fig. 1 Ultrasound source system using acoustic waveguides and a concave type transducer.

3. Axisymmetric Finite Element Simulation

The ANSYS Mechanical package was used for axisymmetric finite element simulation. The simulation model of our proposed system is shown in **Fig. 2**. The concave type PZT piezoelectric transducer (Lead Titanate Zirconate C-213) has a diameter of 40 mm, a spherical curvature of 40 mm and air backing of 3 mm thick. The acoustic medium is water (sound velocity: 1497 m/s, density: 1000 kg/m^3), acoustic waveguides are expressed by air (sound velocity: 343 m/s, density: 1.21 kg/m^3) with thickness of 3 mm.

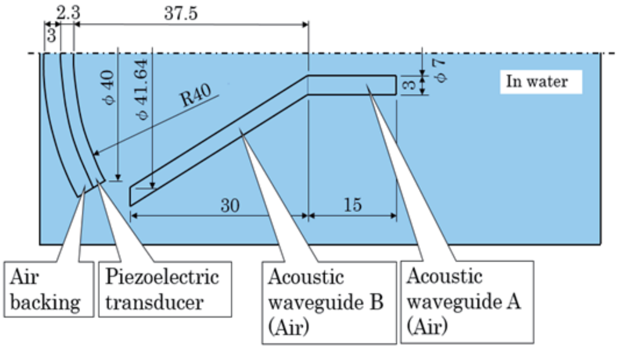

Fig. 2 Axisymmetric Finite Element Simulation model of our proposed ultrasound source system.

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Acoustic waveguide A is the cylindrical type acoustic waveguide, acoustic waveguide B is the conical type acoustic waveguide. Harmonic solution with frequency of 1 MHz and amplitude of 10 V was employed as analysis mode of ANSYS in this study.

4. Simulation Results

We simulated the proposed sourse system as an axisymmetric acoustic field in which the computed output acoustic pressure using only acoustic waveguide A, and both acoustic waveguide A and B. The proposed system was compared with a single transmitting transducer with the same aperture size as the aperture of acoustic waveguide. The results of spatial distributions of acoustic pressure by single transducer are shown in **Fig. 3**, and those by the proposed system with acoustic waveguide A are shown in **Fig. 4**. Those with acoustic waveguide A & B are shown in **Fig. 5**.

To evalute the results, data from the proposed system are overlaid with data from the single transducer. The comparison of the acoustic pressure distributions on the center axis is shown in **Fig. 6**, the comparison of lateral acoustic pressure distributions at 30 mm on the central axis is shown in **Fig. 7**. We calculated the -6 dB beam width, and the rate of increase in peak acoustic pressure of the main beam. The results are shown in **Table I**.

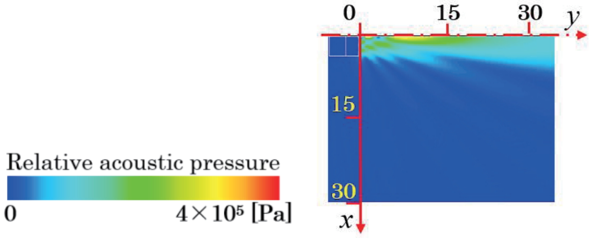

Fig. 3 Spatial distribution of acoustic pressure by single transducer.

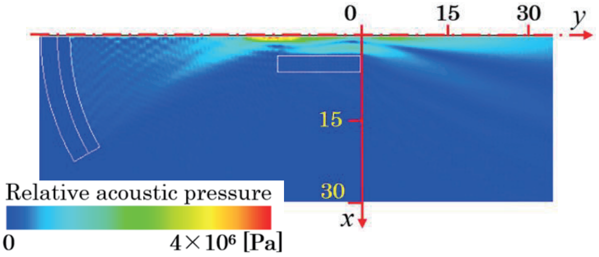

Fig. 4 Spatial distribution of acoustic pressure by the proposed system with acoustic waveguide A.

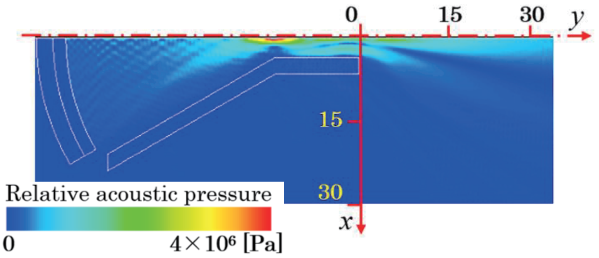

Fig. 5 Spatial distribution of acoustic pressure by the proposed system with acoustic waveguides A & B.

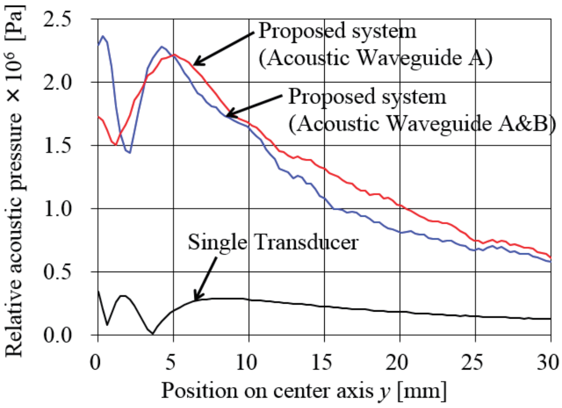

Fig. 6 Comparison of the center acoustic pressure distributions.

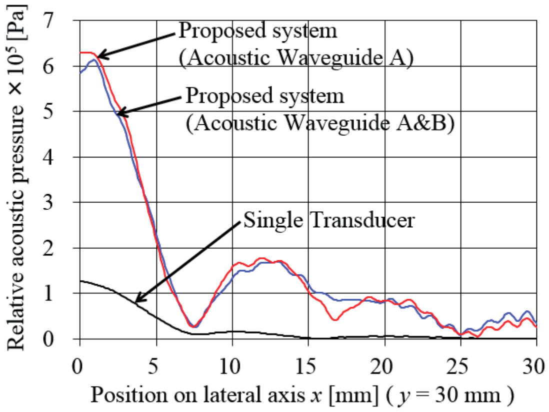

Fig. 7 Comparison of lateral acoustic pressure distributions at 30 mm on the central axis.

Table I Evaluation of acoustic pressure distribution in the lateral direction at 30 mm.

Main beam peak acoustic pressure $P \times 10^3$ [Pa]	Ratio of main beam peak acoustic pressure to single transducer	Main beam width at -6 dB BW [mm]	Ratio of main beam width to single transducer
$P_{A} = 629$	$P_{A} / P_{S} = 4.95$	$BW_{A} = 8.2$	$BW_{A} / BW_{S} = 0.98$
$P_{AB} = 613$	$P_{AB} / P_{S} = 4.83$	$BW_{AB} = 8.4$	$BW_{AB} / BW_{S} = 1.00$
$P_{S} = 127$	–	$BW_{S} = 8.4$	–

Suffix A: Acoustic waveguide A, AB: Acoustic waveguide A&B, S: Single transducer

5. Conclusion

We proposed high intensity ultrasound source system using acoustic waveguides, and simulated using axisymmetric finite element. The proposed system instead of a single transducer, achieved more than 4.8-fold of increasing rate in acoustic pressure at the same beam width.

In the future, we will simulate a model using the larger size concave type transducer. In addition, we will build and test our proposed source system using acoustic waveguides experimentally.

References

1. T. Kikuchi: Jpn. J. Medical Ultrasonics, **36** (2009) pp.637-646.
2. IEC 62127-2 (2007).