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Analysis of Non-uniform Vibration of Focused Ultrasound Transducer Using Time-Reversal Method

位相共役法による集束超音波トランスデューサーの不均一振動の解析

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1. Introduction

In the therapy of High Intencity Focused Ultrasound (HIFU) , ultrasound is generated with piezoelectric transducer made of PZT (lead zirconate titanate). This transducer has a spherical shell in order to focus the acoustic wave energy and coagurate targeted tissues due to heating effect. Idealy, a piezoelectric transducer should vibrate simply in the thickness mode, However,the measured pressure field suggests that the piezoelectric transducer which has a spherical shell doesn't vibrate in the same of the thickness mode [1]. This non-uniform vibration might generate another propagation mode and coagurate not only targeted tissue but also normal tissue. So it is important to investigate cause of non-uniform vibration.

In this study, we measured the ultrasound pressure fields in the focal plane made by two piezoelectric transducers which have different constitution and reconstructed the sound souce distributions using time reversal technique. In addition, two-dimensional Fourier transform apllied to both of the reconstracted sound source distribution and Lamb-like wave[2] examined their propagation modes.

2. Materials and Methods

2.1 Experimental System

We measured acoustic pressure fields about two piezoelectric transducers driven in water and scanned hydrophone (HGL-0400,ONDA). Transducer parameters are listed in **Table I**. One transducer has non-electrode area on its back surface edge and the other has it on its side. In other words, the latter transducer has symmetric disposition of electrode between its front and back surface while the former does not.

2.2 Time-Reversal Method

Fourier Integration at driving frequency was applied to the measured acoustic pressure fields at the each point in propagation plane to reduce the noise level. Calculated complex acoustic pressure is written as

Table I Parameters of Transducer

	Transducer A	Transducer B
Resonance Frequency	3.37 MHz	3.35 MHz
Aperture	24.0 mm	
Focal distance	24.0 mm	
Thickness of PZT	0.69 mm	
Radius of curvature	24.0 mm	
Electrode diameter	24.0 mm	20.0mm
Non-electrode diameter	0.0 mm	2.0 mm

$$p(r,t) = A(r)\exp\left[j\{\omega t + \phi(r)\}\right], \qquad (1)$$

where r is the distance from focus, ω is the driving angular frequency, A is an amplitude, and φ is phase difference from the transmission signal.

Next, we applied time reversal method to the complex acoustic pressure in order to reconstruct sound source distribution. The distribution on the spherical transducer $u(r',t)$ was calculated as

$$u(r',t) = \iint \frac{A(r)}{d(r,\theta,r')}\exp\left[j\left\{\omega\left(t - \frac{d(r,\theta,r')}{c}\right) - \phi(r)\right\}\right] r dr d\theta, \qquad (2)$$

where r' is the radial distance along the transducer surface, and $d(r,\theta,r')$ is the distance from an arbitrary point on the measurement point.

2.3 Vibration Analysis by Two-Dimensional Fourier Transform

To extract the propagation mode from the transducer vibration, two-dimensional Fourier transform applied to $u(r',t)$ and obtained spectra written as

$$H(k,f) = \iint u(r',t)\exp\{-j(kr' + 2\pi ft)\} dr' dt, \qquad (3)$$

where k and f correspond to the frequency in the spatial and time domains.

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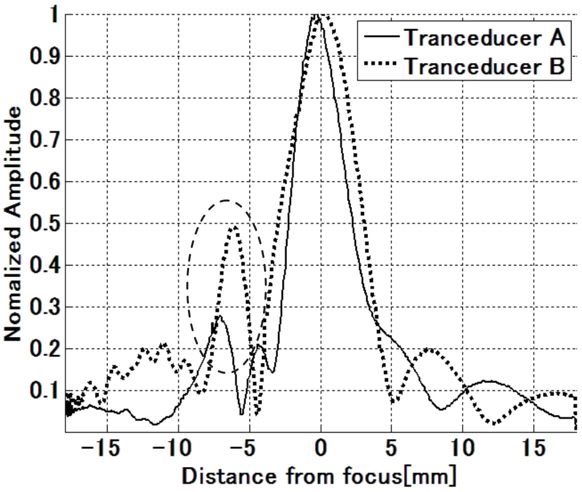

Fig.1 Ultrasound pressure amplitude on the propagation axis

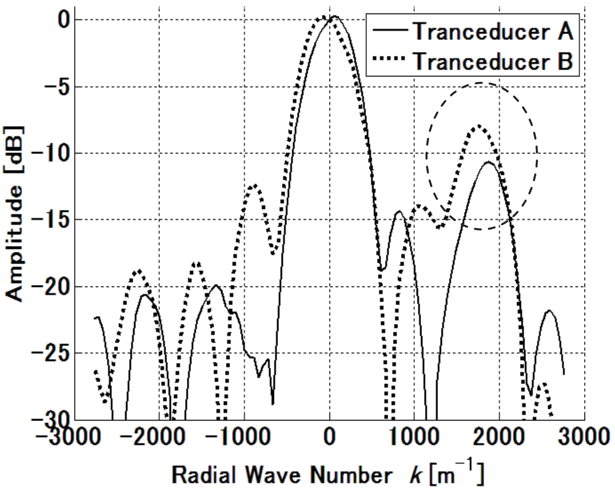

Fig.2 Radial wave number spectrum

3. Results and Discussion

3.1 Ultrasound Pressure Field

Ultrasound pressure fields were measured and calculated on the propagation axis. **Fig.1** shows the pressure amplitude normalized by their maximum amplitudes. Both results have second peaks at 7.0 mm and 6.1 mm (surrounded by broken line). These peaks might influence normal tissue which is in front of targeted tissue. In addition, the results showed that the intensity of nearside lobe using transducer B is smaller than using transducer A.

3.2 Two-Dimensional Fourier Transform

The radial wave number spectra of the experimental data at the driving frequency are shown in **Fig.2**. The largest peak almost corresponds to the uniform thickness vibration. These spectra have second largest peaks at spatial frequency *k* of 1882 m^{-1} and 1760 m^{-1}. These second largest peaks were seen only in the positive spatial frequency domain. These peaks denote that the wave propagates only one direction. In this case, Lamb-like waves were generated and they propagated from the edge of transducer toward center. This mode has the wavelengths of about 3.34 mm and 3.57 mm, respectively. The amplitudes in the decibel scale at second largest peaks are -10.7 dB and -7.9 dB, respectively. The results of the acoustic pressure on the propagation axis contributed to decrease the energy of Lamb-like waves shown at the second largest peaks.

4. Conclusion

We experimentally analyzed the relationship between non-uniform vibration of piezoelectric transducer and disposition of non-electrode on the transducer. Reconstruction of the sound source distribution from a measured acoustic pressure field was calculated using time reversal method, and propagation mode of the non-uniform vibration was analized using two-dimension Fourier transform.

Comparing with results of the radial wave number spectra, there was 2.8 dB difference between the second largest peak by transducer A to B. This propagation mode might be generated the Lamb-like wave and focus its energy in front of the focal point.

However the piezoelectric has symmetric electrode disposition between its front surface to back surface; Tranceducer A, propagation mode of Lamb-like waves exists. This results showed that it’s neccesary to analyze about other parameters of tranceducer in order to annalyze non-uniform vibration and to reduce Lamb-like wave effect.

References

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