ULTRASONIC RESPONSES WITH THE TILT OF THE TRANSDUCERS

PACS REFERENCE: 43.20.El

Author: Tohru Imamura

Institution: National Institute of Advanced Industrial Science and Technology

Complete Address: AIST Tsukuba Central 3, Tsukuba 305-8563, Japan

Tel.: +81-298-61-4204

Fax: +81-298-61-4047

E-mail: tohru-imamura@aist.go.jp

ABSTRACT: Ultrasonic responses with the tilt of a pair of square flat transducers are investigated and are computed. The amplitude distribution of the mean sound pressure, mean sound particle velocity and mean specific acoustic impedance are all derived and are explained with the phase delay distribution of them. The needed computational time increases with the value of a/λ (a: half side length of the square, λ: wavelength of the ultrasound), because the field complexity increases with the value of a/λ. The computation is done up to the case, where $a/\lambda = 5.0$.

INTRODUCTION: Ultrasonic field by finite dimensional transducers has long been extensively analyzed, as it has much complexity with diffraction.[1), 2)] Effect of tilt against the transmitting transducer on the receiving transducer is rather remarkable.[3)] But, it has not yet been fully investigated in detail, because the effect of tilt differs from the symmetrical ultrasonic field analyses. In this paper, ultrasonic responses with the tilt of the transducer are presented in the case for a pair of square flat transducers. Sound pressure, sound particle velocity and specific acoustic impedance are all computed with the numerical quadruple integration.

FUNDAMENTAL EQUATIONS OF THE ULTRASONIC FIELD: The medium of ultrasonic propagation is assumed as usual to be isotropic and non-absorptive. In this condition, the transmitting transducer is set to move coherently with a sinusoidal manner, then the amplitude of the sound particle velocity is set to be $\dot{v}_0$ and the angular frequency of the ultrasonic wave is set to be ω. The sound pressure on the receiving transducer by the contribution of the whole transmitting transducer can be explained as

$$\dot{p} = \dot{v}_0 \exp(j\omega t)\rho c\left(\frac{j}{\lambda}\right)\iint_{S'} \frac{\exp(-jkd)}{d} dS'$$

$$\equiv \dot{v}_0 \exp(j\omega t) r \exp(-j\theta)$$

In Eq. (1), ρ is the density of the medium, k the wave number, d the distance between a point on the transmitting transducer and a point on the receiving transducer. Then, the mean sound pressure over the receiving transducer is expressed as

$$\dot{p}_m = \dot{v}_0 \exp(j\omega t)\iint_S r \exp(-j\theta) dS \quad (2)$$

$$\equiv \dot{v}_0 \exp(j\omega t) r_m \exp(-j\theta_m) \quad (2)'$$

The z component of the sound particle velocity on the receiving transducer by the contribution of the whole transmitting transducer can be explained as

$$\dot{v}_z = \dot{v}_0 \exp(j\omega t)\left(\frac{1}{2\pi}\right)\iint_{S'} \frac{z(1+jkd)\exp(-jkd)}{d^3} dS' \quad 3)$$

$$\equiv \dot{v}_0 \exp(j\omega t) r_D \exp(-j\theta_D)$$

Then, the mean sound particle velocity over the receiving transducer is expressed as

$$\dot{v}_{zm} = \dot{v}_0 \exp(j\omega t)\iint_S r_D \exp(-j\theta_D) dS \quad (4)$$

$$\equiv \dot{v}_0 \exp(j\omega t) r_{Dm} \exp(-j\theta_{Dm}) \quad (4)'$$

The mean specific acoustic impedance over the receiving transducer is expressed as

$$Z_{Szm} = \frac{r_m}{r_{Dm}} \exp[-j(\theta_m - \theta_{Dm})] \quad (5)$$

ULTRASONIC RESPONSES WITH THE TILT OF A PAIR OF SQUARE FLAT TRANSDUCERS: The ultrasonic system investigated here is shown in Fig. 1. Both the transmitting transducer and the receiving transducer have a same square flat shape.

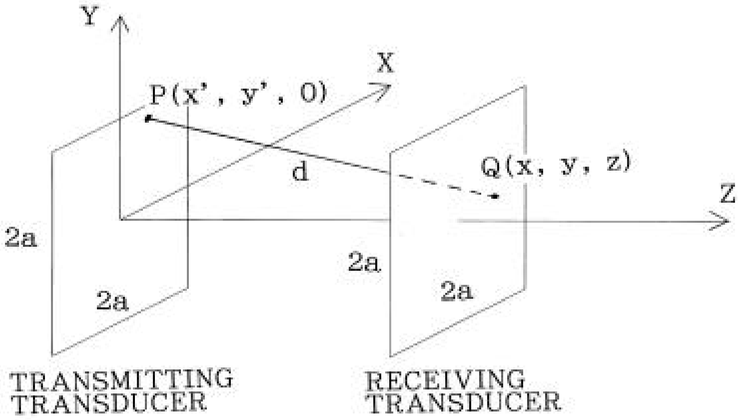

Fig.1 Coordinate system used in the analysis.

The paper analyzes the ultrasonic responses with the tilt of a pair of square flat transducers. Figure 2 shows the sound particle velocity, where a/λ=5.0 on condition that the ultrasonic wave travels as a plane wave. The horizontal axis indicates the tilting angle of the receiving square flat transducer against the transmitting square flat transducer. The range of tilt is from zero to $\pi/8$. The vertical axes indicate the relative amplitude and the phase delay, respectively. The relative amplitude when the tilting angle is zero has a maximum value of 1.0. It indicates zero at three points along the horizontal axis within the range up to the place when the tilting angle is $\pi/8$. At these tree points, the phase delay always leaps by π.

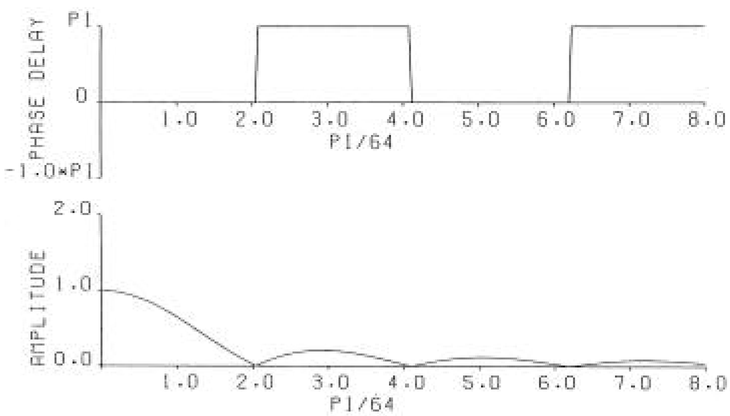

Fig.2 SOUND PARTICLE VELOCITY
PLANE WAVE
A/LAMBDA=5.0

Figure 3 shows the sound pressure, when the distance between the transducers is the unit length (a). Figure 4 shows the sound particle velocity when the distance between the transducers is the unit length (a). Figure 5 shows the specific acoustic impedance when the distance between the transducers is the unit length (a). The sound pressure and the sound particle velocity indicate a similar tendency, which are deductible from the sound particle velocity on condition that the ultrasound travels as a plane wave. But, the specific acoustic impedance indicates clearly the difference between the sound pressure and the sound particle velocity.

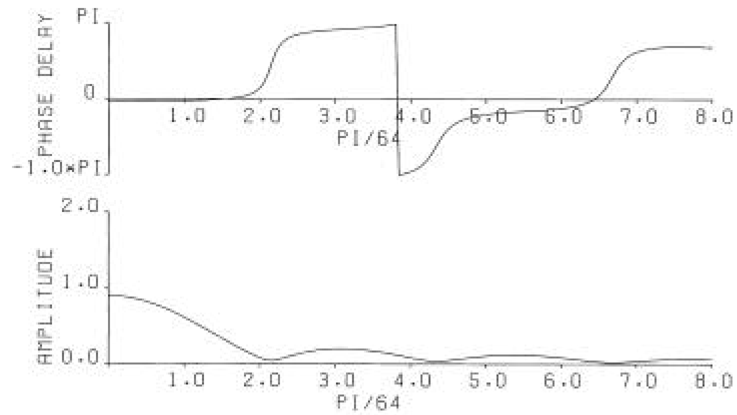

Fig.3 SOUND PRESSURE
SQUARE TRANSMITTER
SQUARE RECEIVER(Z=A)
A/LAMBDA=5.0

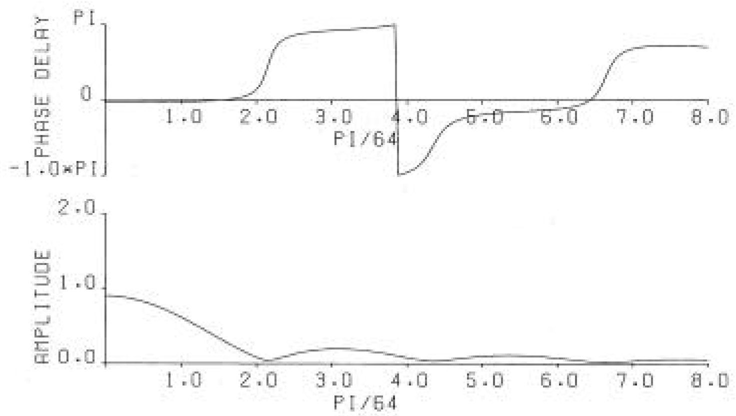

Fig.4 SOUND PARTICLE VELOCITY
SQUARE TRANSMITTER
SQUARE RECEIVER(Z=A)
A/LAMBDA=5.0

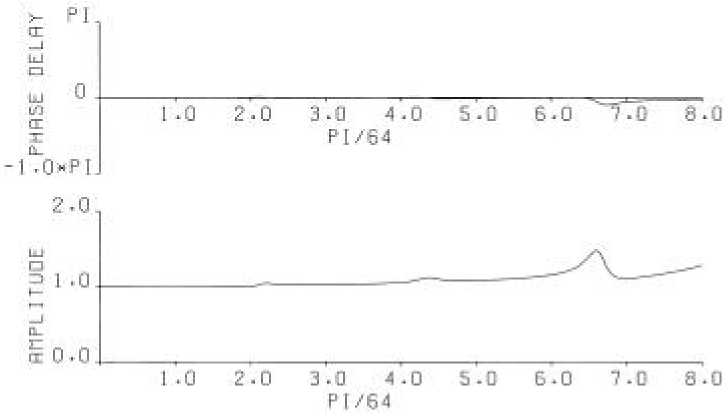

Fig.5 SPECIFIC ACOUSTIC IMPEDANCE
SQUARE TRANSMITTER
SQUARE RECEIVER(Z=A)
A/LAMBDA=5.0

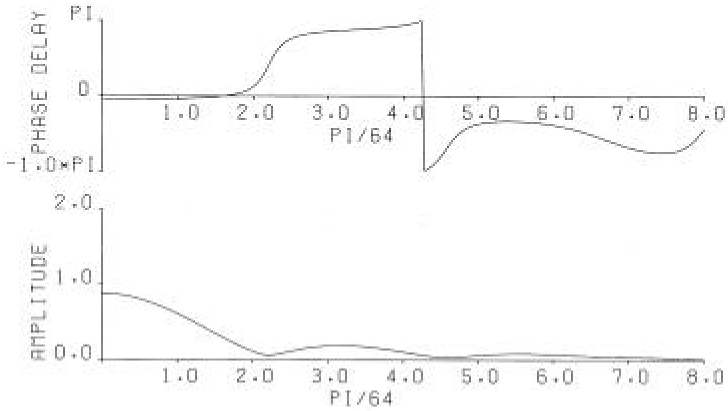

Fig.6 SOUND PRESSURE
SQUARE TRANSMITTER
SQUARE RECEIVER(Z=2A)
A/LAMBDA=5.0

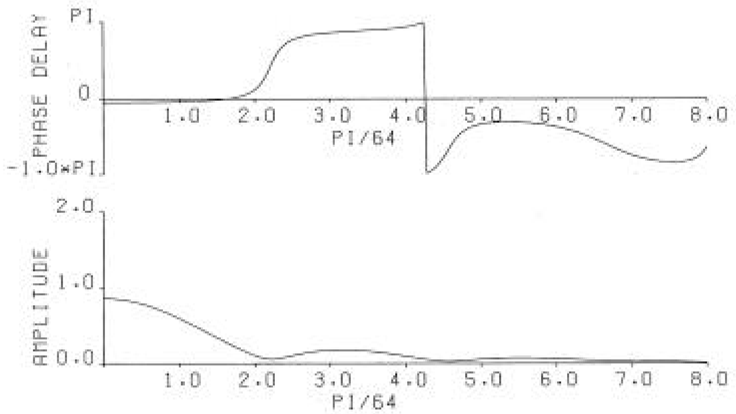

Fig.7 SOUND PARTICLE VELOCITY
SQUARE TRANSMITTER
SQUARE RECEIVER(Z=2A)
A/LAMBDA=5.0

Figure 6 shows the sound pressure when the distance between the transducers is 2a. Figure 7 shows the sound particle velocity when the distance between the transducers is 2a. Figure 8 shows the specific acoustic impedance when the distance between the transducers is 2a.

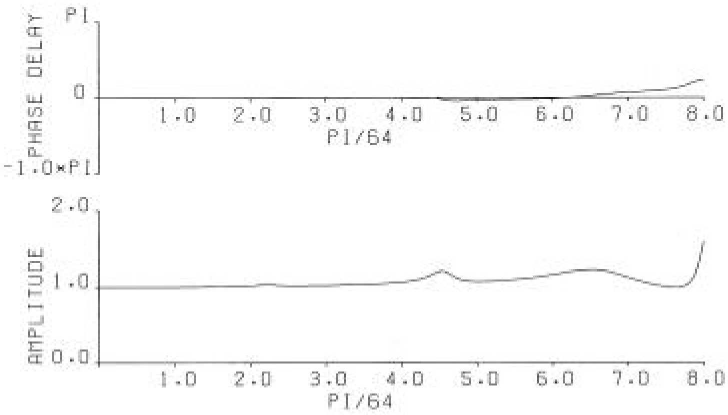

Fig.8 SPECIFIC ACOUSTIC IMPEDANCE
SQUARE TRANSMITTER
SQUARE RECEIVER(Z=2A)
A/LAMBDA=5.0

CONCLUSION: The effect of tilt on the ultrasonic responses with a pair of finite flat transducers is remarkable. It has not yet been fully investigated, because the analyses for these ultrasonic fields seem to be much complicated. The investigation with the system of a pair of circular flat transducers becomes very difficult, if the ultrasonic field system to be analyzed differs from the axial symmetry. The typical example is the tilt of the receiving flat transducer. For the system of a pair of square flat transducers, numerical quadruple integration can be effectively applied even including the transducer tilt. By the numerical method, the ultrasonic responses with the tilt of the square flat transducer are investigated up to the case, where $a/\lambda=5.0$.

REFERENCES:

1) H. Seki, A. Granato and R. Truell: "Diffraction effects in the ultrasonic field of a piston source and their importance in the accurate measurement of attenuation," J. Acoust. Soc. Am., 28 (1956) 230-238.
2) T. Imamura: "Specific acoustic impedance of the ultrasonic field by the circular flat transducers," Ultrasonics, 36 (1998) 751-757.
3) T. Imamura: "Ultrasonic field analysis by numerical quadruple integration with repeated trapezoidal rule," Proc. Joint Meeting of 137th Acoust. Soc. Am. & 2nd Convention EAA, (1999) 4APAA12.