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Measurement of Transient Ultrasound Fields on Vibrating Surface Using Optical Phase Retrieval

光位相回復法を用いる振動面上の非定常音場計測

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1. Introduction

It is important to measure the vibrational distribution of the vibrating surface for assessment of the ultrasound transducer. To obtain the vibrational distribution of the vibrating surface, measurement of the sound pressure on the surface has been performed. To obtain the sound pressure on the surface, measurement method using acoustical holography has been reported. [1)] In this method, the pressure distribution on the vibrating surface is measured by backpropagation of the ultrasound measured on arbitrary measurement plane. The sound pressure on the arbitrary measurement plane is measured by a hydrophone. However, the hydrophone disturbs the measured acoustic field. To avoid such problem, several optical measurement method, such as the method using Raman-Nath diffraction[1)] and that using interferometer[2)], were proposed. However, former method cannot be applied for the measurement of transient ultrasound fields and the latter method is sensitive to vibration and it requires precise arrangement of the optical system.

We focus on the Fresnel phase retrieval method as the measurement method of sound pressure distribution[3)]. In this method, light is irradiated into the ultrasound and diffracted by the phase grating formed by the ultrasound. Light phase delay which is proportional to ultrasound pressure is obtained from light diffraction pattern. This method can measure transient ultrasound without using hydrophone. We proposed a measurement method of vibrating surface using the light phase retrieval. Sound pressure distribution on the arbitrary measurement plane is measured using phase retrieval and CT method. The transient vibrational distribution of vibrating surface is obtained by using backpropagation of temporal measured transient ultrasound fields. In this paper, as a fundamental study, measurement of transient ultrasound fields using phase retrieval method was performed.

2. Theory

Figure 1 shows the outline of the proposed method. Vibrating surface locates in xy plane, which forms the transient ultrasound fields by emitting the burst ultrasound. Light beam is

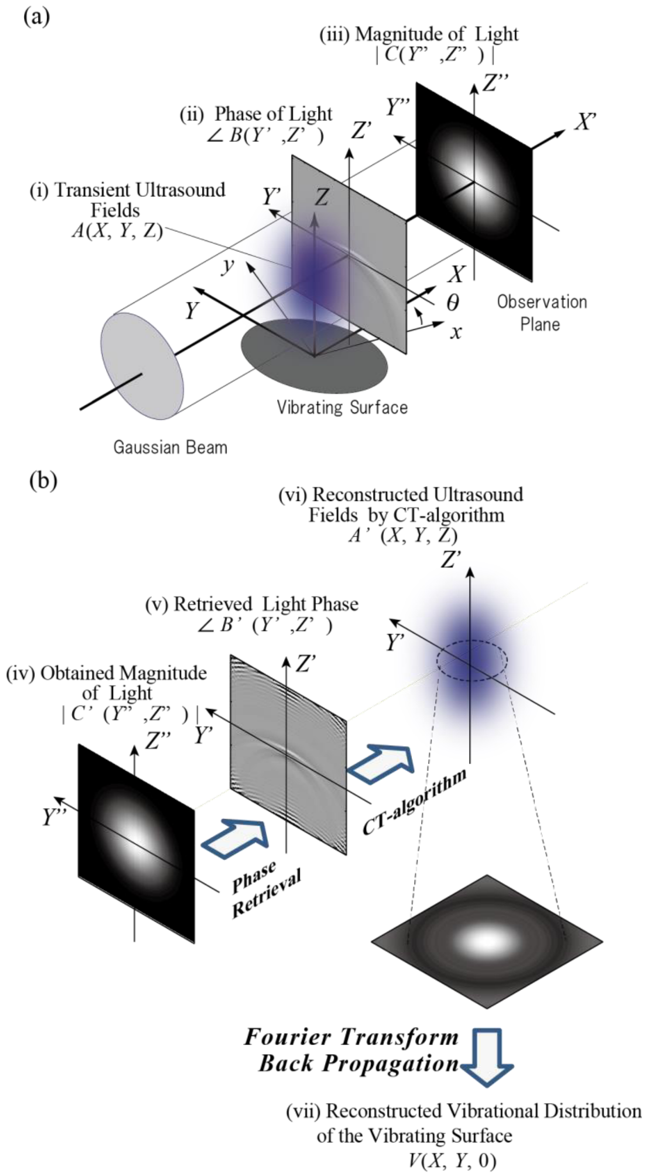

Fig. 1 Outline of the proposed method.
(a) Numerical setup and (b) Estimation process.

irradiated normally to the transient ultrasound fields. The refractive index is changed by the pressure in water. The projection of phase change of light along the *x*-axis $B(Y', Z')$ is

$$B(Y', Z') = \frac{2\pi\kappa}{\lambda}\int A(X', Y', Z')\,\mathrm{d}X'$$

where κ ,λ and A are acousto-optic coefficient, wavelength of the light, and sound pressure distribution, respectively. The transient ultrasound is estimated by obtaining $B(Y',Z')$. However, photo-detector cannot measure light phase directly because of its low response time. Therefore, optical phase delay cannot be obtained. Then, phase retrieval is applied to obtain optical phase. Phase retrieval is a method to estimate the phase information from intensity information on two arbitrary planes. The Fresnel diffraction pattern of light beam which passed through ultrasound fields is simulated. Light phase shift caused by the ultrasound is estimated from two light intensity of incident light beam and passed light beam. Formed transient ultrasound fields was symmetry at z axis, three dimensional transient ultrasound fields was reconstructed by using the computerized tomography using projection of estimated light phase distribution. The acoustical pressure distribution on the vibrating surface is estimated by performing backpropagation of the optically measured acoustical wave using acoustical holography.

Sound pressure distribution on xy plane was obtained by backpropagation of each frequency component of optically measured sound fields. Relationship between sound pressure distribution and particle velocity distribution along z-axis is

$$\frac{\partial A'}{\partial Z'} = -\rho \frac{\partial V}{\partial t},$$

where ρ and f are the density of the medium, time, respectively. Therefore, particle velocity distribution at vibrating surface can be calculated from sound pressure distribution at arbitrary measurement plane.

3. Simulation

Figure 1 shows numerical simulation set up. Transient ultrasound field was formed by vibrating surface. The diameter of the vibrating surface was 3 mm. Vibrating surface moves along z-axis and piston action was assumed. The transducer was driven with 2 cycles at 2MHz in center frequency. A light beam generated by He-Ne light source operating at 632.8 nm in vaccume wavelength passed through at z = 7.7 mm. The diameter of light beam was 6 mm. The propagation distance between the ultrasound fields and observation plane was 300 mm. Optical diffraction occurring during traversal of the sound field was neglected.

4. Results and discussion

Figure 2 (a) shows the phase delay of light which passed the ultrasound fields. Fig. 2 (b) shows the estimated phase delay using phase retrieval method. We have found that the phase

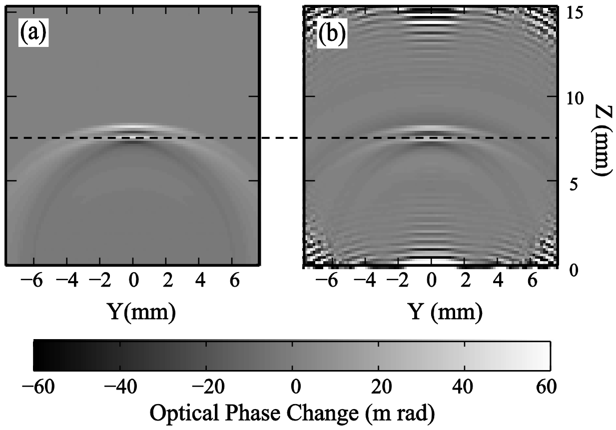

Fig.2 Optical phase change caused by burst ultrasound. (a) Theoretical, and (b) Phase retrieval

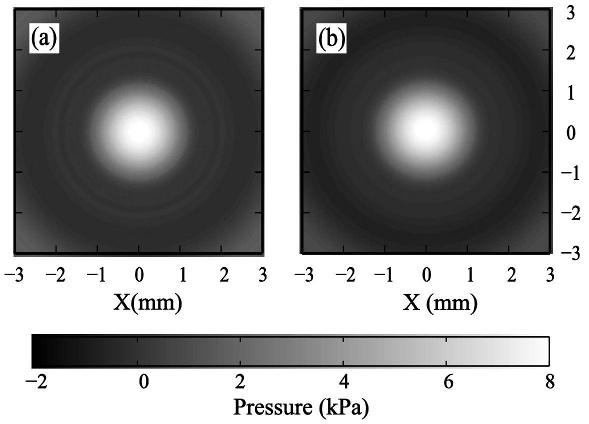

Fig.3 Sound pressure distribution

could be retrieved successflly in specific area, which is necessary for backpropagation. **Figure 3** (a) shows the sound pressure distribution at the area of dashed line in Fig. 2. Figure 3 (b) shows the estimated sound pressure distribution. These results are in good agreement. Therefore, sound pressure distribution at transient ultrasound fields was measured by using light phase retrieval.

5. Conclution

The non-contacting measurement of vibrating surface using light phase retrieval was proposed. In this paper, measurement of transient ultrasound fields using phase retrieval was performed. The obtained results suggests the possibility of the visualization of the transient vibrational distribution of the vibrating surface.

References

1. T. Ohbuchi *et al*: Jpn. J. Appl. Phys. **46** (2007) 4649.
2. M.Yoshioka *et al*: Symposium on ultrasonic electronics Proceedings. **19** (1998) 243.
3. Todd A.Pitts *et al*: Ultrasonics, Ferroelectrics and Frequency Control, IEEE Transactions. **50** (2003) 8.