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Fresnel Diffraction Pattern of Laser Passing through Transient Ultrasound Fields

非定常音場を通過したレーザー光のフレネル回折パターン

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1. Introduction

Ultrasonic waves are widely used for medical inspection, non-destructive testing, oceanographic survey, and other applications. It is important to measure the ultrasound fields emitted from the transducer for the assessment of the transducer performance. Measurement method of the ultrasound fields using light probe is attractive because it allows non-contact inspection. Although the transient signal is widely used for non-destructive testing, measurement of the transient ultrasound fields has not actively been reported. Some studies have reported the measurement of the transient ultrasound fields using the Shclieren and optical beam deflection method[1,2]. These methods can measure the ultrasound fields accurately, however the precise design of the optical system is required.

In this study, we focus on the simple measurement method using the interference of a diffracted light[3]. The light transmitted through the ultrasound fields generates a Fresnel diffraction pattern in the near field. The measurement of complex ultrasound fields has been achieved by detecting the light intensity change at one point on the Fresnel diffraction pattern. However, the previous method has only been applied for the measurement of the steady-state ultrasound fields. The transient ultrasound fields may result in a more complicated diffraction pattern[4]. As the basic study for the measurement of the transient ultrasound fields using above technique, measurement of the Fresnel diffraction pattern when the laser beam intersects the transient ultrasound fields was performed in this paper.

2. Theory

When the ultrasound intersects the laser beam, Raman-Nath diffraction is occurred. The diffraction wave of each order appears with a constant angle formed from the optical axis. The angle between n-th order diffraction wave and optical axis, θ_n, is given by

$$\theta_n = nl/\lambda \tag{1}$$

where, n, l, and λ are the diffraction order, the ultrasound wavelength, and the light wavelength, respectively. In the optical setup in **Fig. 1**, the diffracted wave of 0th order and ±1st order interferes each other. Previous study has been reported that the light intensity changes with the ultrasound frequency at the place where diffracted wave interferes each other. On the other hand, the more complicated diffraction pattern is occurred when a part of the laser beam intersects ultrasound fields. Therefore, above formula cannot be applied directly to transient ultrasound fields. Fresnel diffraction pattern follows the following formula, which is an approximation of Kirchhoff-Fresnel diffraction[5], the complex amplitude distribution of the light on the observation plane, g, is given by

$$g(x,y) = \frac{1}{\mathrm{i}\lambda z}\exp\left\{\mathrm{i}k\left(\frac{x^2+y^2}{2z}\right)\right\}$$
$$\mathrm{F}\left\{g'(x',y')\exp\left\{\mathrm{i}k\left[\frac{(x'^2+y'^2)}{2z}\right]\right\}\right\} \tag{2}$$

where g' and k are the complex amplitude distribution of the light on the input plane, and the wavenumber of the light, respectively. The symbol ‘F’ means the Fourier transform. The light intensity distribution, I, is given by

$$I(x,y) = |g(x,y)|^2. \tag{3}$$

Steady-state ultrasound fields are derived by one point measurement on the Fresnel diffraction pattern. On the other hand, transient ultrasound fields are derived by multiple point measurements to obtain the Fresnel diffraction pattern.

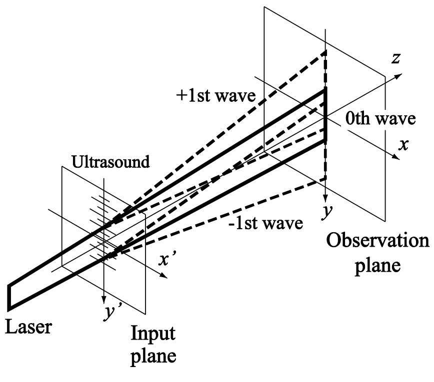

Fig. 1 Principle of laser diffraction caused by ultrasound.

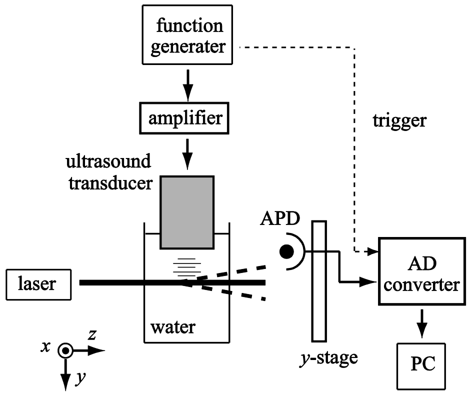

Fig. 2 Schematic diagram of experimental setup.

3. Experiment

We measure the difference between the light intensity pattern with and without ultrasound in experiment. A schematic diagram of the experimental setup is shown in **Fig. 2**. The light source is a He-Ne Laser of 632.8 nm in wavelength with output power of 15 mW. The laser light is incident normally upon the acoustic beam. Ultrasound fields were irradiated with the laser beam which was expanded by propagating arbitrary distance so that many ultrasonic waves might intersect laser beam. The relationship between the beam size and propagation distance is given by

$$w = w_0 \left[1 + \left(\frac{4\lambda z}{\pi w_0{}^2}\right)^2\right]^{\frac{1}{2}} \qquad (4)$$

where w, w_0, and z are the diameter of a laser beam after laser propagation, the diameter of a laser beam at beam waist, and the propagation distance of laser beam, respectively. In the experiment, the distance between the beam waist and the acoustic beam axis was 1.7 m, and the diameter of the laser beam waist was 1.9 mm. The distance between the acoustic beam axis and the observation plane was 1.25 m. A function generator output a sinusoidal wave at a frequency of 5 MHz in frequency with 10 cycles to drive the ultrasound transducer. The light intensity on the observation plane behind the acoustic axis was measured by a photo-detector. In the above experimental setup, light intensity pattern measurements were performed by scanning the photo-detector along the y-axis, which was triggered by the synchronous output of the function generator.

4. Results and Discussions

The temporal change of the light intensity pattern is shown in **Fig. 3**. The changes of the light intensity pattern and the interference fringes were observed in Fig. 3 (d). It is considered that the interference fringes were formed by interference of the 0th and the ±1th diffracted wave. There was a difference between diffraction pattern when the ultrasound enters and exits from the region irradiated by the laser, which correspond to Figs. 3 (b) and, 3(f). The diffraction pattern became partially asymmetric and more complicated pattern than that of continuous wave case.

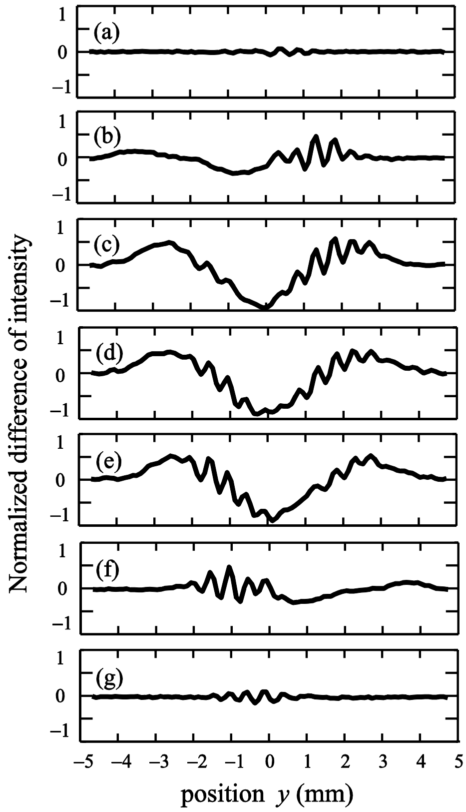

Fig. 3 Temporal change of the light intensity pattern; (a)-(g): patterns at 12.4 to 16.0 (us) every 0.6 us after ultrasound burst generation.

5. Conclusion

The measurement of Fresnel diffraction pattern when the laser beam intersects the transient ultrasound fields was performed. As a result, the observed diffraction patterns in transient ultrasound fields were different from those in steady-state ultrasound fields. Further investigations are planned to estimate transient ultrasound fields.

References

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