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Proceedings of Symposium on Ultrasonic Electronics, Vol. 35 (2014) pp. 3-4
3-5 December, 2014

Visualization of Acoustic Evanescent Waves by Photoelastic Method
光弾性法を用いた音響エバネッセントン波の光学的可視化

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1. Introduction

It is well known that the evanescent wave is produced when an incident wave hits the interface at the angle that is larger than the critical angle and exhibits an exponential decay within the refractive medium. The evanescent waves have been studied by many scientists and attracted a lot of attention as technology in expanded into the nano region[1-4]. In acoustics, a number of basic studies about the evanescent wave were reported by researchers[5-7]. Applications of acoustic evanescent waves have been found in the development of loudspeaker[8] a planar array[9] and acoustic transducer[10]. However, wave propagation phenomena of the evanescent waves are hardly understood visually.

Visualization of ultrasonic waves is helpful for understanding wave propagation in transparent media. Stroboscopic ultrasonic visualizations, such as the Schlieren technique[11, 12], Fresnel method[13], photoelastic method[14-16], and the sensitive tint visualization method[17] have been used to find solutions to the problems encountered in ultrasonic non-destructive testing and the evaluation of probe design and performance. In this paper, we report the visualized acoustic evanescent waves at about 1 MHz generated at the water/glass boundary by the stroboscopic photoelastic method.

2. Experiment

Figure 1 shows a schematic diagram of a visualization system using a stroboscopic photoelastic technique to observe acoustic evanescent waves. The transparent elastic plate in which evanescent waves propagate is made from BK7 optical glass. In the photoelastic optical system, polarizing plates (polarizer P and analyzer A) approximately satisfying the condition of crossed Nicols are inserted between lenses L2 and L3. The first quarter-wave ($\lambda/4$) plate is placed in between the polarizer and the specimen and the second quarter-wave plate is placed between the specimen and the analyzer. The camera senses the light with the polarization plane rotated by the stress caused by the ultrasonic wave. The white stroboscopic light source with a pulse width of 180 ns is driven at about 60 Hz, synchronized to the excitation of the ultrasonic wave. A delay between the light emission and the excitation of the ultrasonic wave can be set, and a still image with an arbitrary duration in time can be obtained. Furthermore, by continuously increasing the delay, slow motion video recording is possible. The Fresnel diffraction method can be used concurrently to visualize the ultrasonic wave in the water. Therefore, it is possible to observe simultaneously the evanescent wave in the glass plate and the incident and reflected waves in the water. BK7 optical glass plate with thickness of 10 mm, length of 150 mm, and width of 40 mm are placed in the water parallel to the *x* axis. Evanescent waves are excited by ultrasonic waves impinging over the critical angle. A distribution of the stress due to evanescent waves appears in the glass plates, and a periodic distribution of the refractive index appears in the water. Slightly changing from the orthogonal condition between P and A to give a bias by leakage light, wavefronts separated by a distance of one wavelength and the refractive index distribution of ultrasonic waves in the water can be visualized.

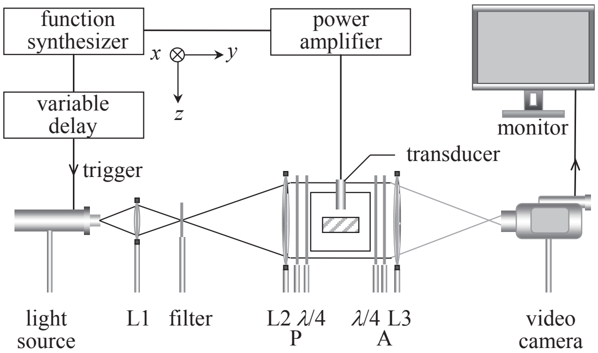

Fig. 1 Experimental setup for the visualization system of the stroboscopic photoelastic technique.

3. Results and discussion

A typical ultrasonic wave in water and evanescent wave in the glass plate visualized by the stroboscopic photoelastic method are shown in figure 2. The upper four-fifth domain is the water, the lower fifth domain is the glass plate, and the

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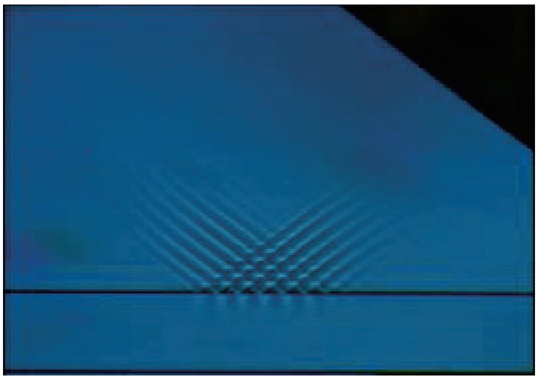
interface is visualized by a black horizontal line. The transducer, shown in the upper right area in Fig. 2, is a single-element longitudinal wave transducer with a quarter wavelength layer acoustically matched to water. In Fig. 2 (a) a 34-mm-wide tone-burst ultrasonic wave at 0.93 MHz with duration of about 8 μs is incident on the water-glass boundary at an angle of 36 degrees off the normal line of the surface. The angle of incidence is larger than the critical angle calculated from $\sin^{-1}\left(c_{\mathrm{W}}/c_{\mathrm{S}}\right)$. The velocities of longitudinal wave in water and shear wave in the glass (BK-7) are $c_{\mathrm{W}} = 1500\ \mathrm{ms}^{-1}$ and $c_{\mathrm{S}} = 3630\ \mathrm{ms}^{-1}$, respectively. Thus we can estimate the critical angle at 24 degrees. In Fig. 2 (b) the superposition pattern of the incident wave and the reflected wave at the upper surface of the glass plate is shown clearly. Simultaneously in the glass plate in Fig. 2 (b) the evanescent wave localized at the glass-side interface is visualized. The evanescent wave rapidly decays in the glass away from the interface. In our experimental conditions, the brightness of the visualized image is roughly proportional to the square of the acoustic stress in the glass.

(a) The incident wave



(b) The acoustic evanescent wave

Fig. 2 Visualized acoustic evanescent wave by the stroboscopic photoelastic method.

We have reasonable grounds for believing that the visualized wave is the evanescent wave.

・The incident wave hits the interface over the critical angle.

・The brightness of the wave decays exponentially in the $-z$ direction.

・The wave doesn't travel, i.e., the wave is not the Rayleigh wave. We have already visualized the Rayleigh wave propagating along the glass surface with its phase velocity and leaking the energy into the water, excited by the incident wave impinging at near critical angle.

・The wave length of the wave changes depending on the incident angle.

4. Conclusion

We have obtained acoustic evanescent waves produced when the propagating incident wave impinges on the water/glass interface at post-critical angle using the stroboscopic photoelastic method.

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