Visualization of High Frequency Ultrasonic Wavefronts by Holographic Interferometry

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MASAHIRO UEDA, YOSHIHIRO OSHIDA, KOICHI IWATA, AND RYO NAGATA

Abstract—**Ultrasonic fields in glycerol are visualized by holographic interferometry with a phase-modulated reference beam. Fine particles suspended in glycerol are illuminated with sheetlike light, and the light scattered from the illuminated plane is recorded in a hologram. The ultrasonic field on the plane is displayed in the reconstructed image, which provides equiphase positions of the wave, i.e., wavefronts. The experiments are done with an ultrasound of frequency 1 MHz. The wavefronts of the ultrasounds scattered or reflected by obstacles are visualized on some cross-sectional planes. The experiments demonstrate that the method can visualize the three-dimensional ultrasonic fields.**

Introduction

In [1] and [2] we proposed a method for visualizing a progressive ultrasonic wave in the interior of a transparent medium and also verified it with a preliminary experiment with a 200-kHz ultrasound. We have emphasized from a theoretical consideration that this method is applicable to ultrasonic waves with frequencies up to 6 MHz [2].

Wavefront visualization is important, for example, in designing and evaluating transducers and acoustic lenses for nondestructive testing and medical imaging [3]. A few megahertz ultrasound is usually used in these applications. In this paper we shall demonstrate some examples of wavefront visualization of 1 MHz ultrasound and show that the method can be used for these applications.

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II. Method and Experiment

This method uses linearized subfringe interferometric holography developed by Metherell [4]. In this method we make a time-average hologram with a sinusoidally phase-modulated reference wave. The modulation is obtained by using the reference light, which is reflected by a mirror vibrating at the same frequency as the object. By adjusting the vibration amplitude of the mirror, we can detect very small (subfringe) vibration.

Metherell used this method for visualizing ultrasound. He adopted a thin film as an acoustooptic interface that vibrates in accordance with the ultrasonic wave. Light scattered by the film is recorded on the hologram. In the present method, we suspend fine particles in the transparent medium in which the ultrasound propagates. The particles vibrate in accordance with the ultrasound. When we illuminate the medium with sheetlike light, the particles in the illuminated plane scatter light. Thus the illuminated sectional plane plays the role of the acoustooptic interface. We can easily set the plane to be examined without affecting the ultrasonic field.

In the linearized subfringe interferometric holography, the intensity of the reconstructed image depends on both the amplitude and phase of the object vibration. If the amplitude varies slowly in space compared with the phase, the reconstructed image exhibits equiphase positions of the vibration. For a progressive ultrasonic wave, this condition is usually satisfied so that we can visualize its wavefronts.

In the previous experiment we mainly used gelatin in gel state as a transparent medium. However, it is desirable to use liquid for usual applications. The liquid used in this experi-

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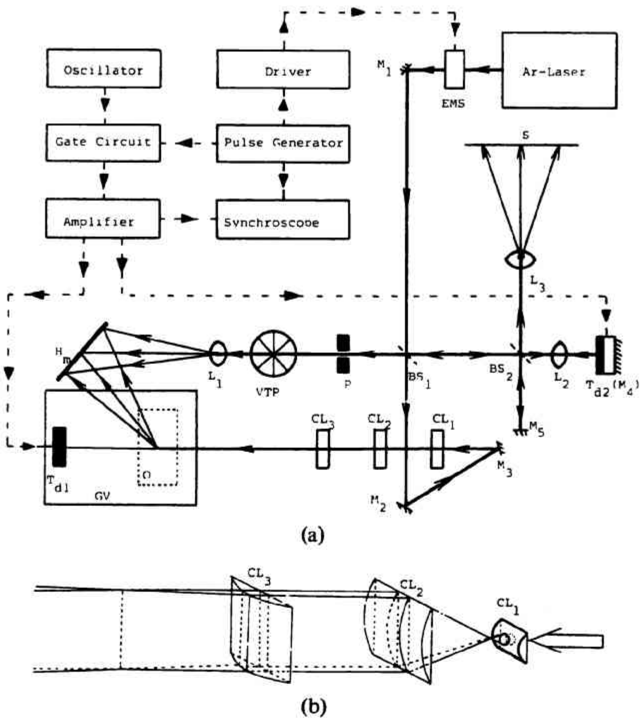

Fig. 1. (a) Experimental setup: L, lens; M, mirror; CL, cylindrical lens; BS, beam splitter; EMS, electromagnetic shutter; S, screen; T_d, transducer; H_m, hologram; GV, glass vessel; O, obstacle; VTP, variable transmittance plate. (b) Optical system for making light sheet.

ment is glycerol. When an ultrasonic wave is propagated in a liquid, a flow is caused by the radiation pressure of ultrasound. The flow has some influence on the reconstructed fringes. To eliminate this undesirable effect, exposure time must be reduced to a few ms. We used an Ar laser (output power 750 mW) to obtain sufficient light energy for the short exposure time.

Fig. 1(a) shows the optical and electrical arrangement for the experiments. The ultrasonic wave field to be visualized is generated in a glass vessel (GV) of 100 × 120 × 150 mm^3 volume filled with glycerol. In order to suppress reflections of the sound wave, an artificial lawn is placed on all walls except entry and exit through which the laser light is transmitted. The fine alumina particles suspended in glycerol are forced to vibrate by the sound field generated by a barium titanite transducer T_{d1} (40-mm diameter).

The other transducer T_{d2} (10-mm diameter) is also driven by the same oscillator as T_{d1}. A small mirror (4-mm diameter) is attached to T_{d2} and used to modulate the phase of the reference beam. The Twyman-Green interferometer composed of T_{d2}, beam splitter BS_2, mirrors M_4 and M_5, objective lenses L_2 and L_3, and screen S is used for monitoring the vibration amplitude of T_{d2}. It is adjusted to about $\lambda/9$ (λ = 514.5 nm) so that the maximum sensitivity can be obtained [4]. The intensity of the reference wave is adjusted by the variable transmittance plate (VTP).

An electromagnetic shutter (EMS) is driven by the pulse generator, which also opens the gate and allows the 1-MHz electrical signal generated by the oscillator to drive the transducer. The sheetlike light is formed through a cylindrical lenses CL_1, CL_2, and CL_3, as shown in Fig. 1(b). The width of the sheet is about 60 mm and the thickness is about 0.2 mm.

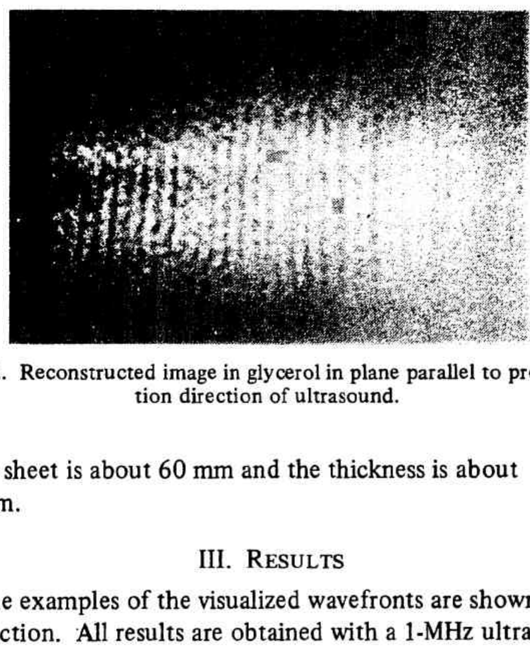

Fig. 2. Reconstructed image in glycerol in plane parallel to propagation direction of ultrasound.

III. Results

Some examples of the visualized wavefronts are shown in this section. All results are obtained with a 1-MHz ultrasound. In all the figures, the intervals of the bright fringes are about 2.0 mm, which agrees with the wavelength calculated from the propagation velocity (1920 m/s at 10°C) and the frequency (1 MHz).

Fig. 2 shows the reconstructed image with no obstacles in the ultrasonic field. We can see the ultrasound propagating from right to left. The wave is planar because of the high frequency and the large transducer.

Fig. 3 shows wavefronts with various obstacles in the medium. In Fig. 3(a) a small glass vessel is placed in front of the transducer. The lower half of the vessel is filled with glycerol

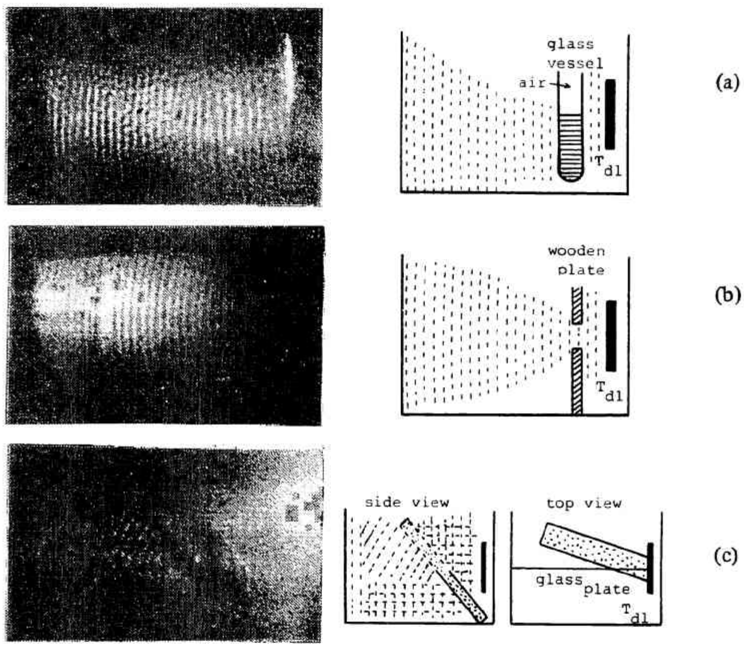

Fig. 3. Reconstructed images of ultrasonic fields with obstacles. (a) Partly filled vessel in front of transducer. (b) Wooden plate with circular opening in front of transducer. (c) Glass plate inclined by 45° to propagation direction.

and the upper half with air as shown in the schematic diagram. The reconstructed image shows that the ultrasound does not transmit through the upper part of the vessel. The transmitted wave in the lower part gradually spreads out into the shaded area in the left part of the image. Fig. 3(b) is the wavefront when a wooden plate of 3-mm thickness with a circular aperture of 10-mm diameter is placed in front of the transducer. The reconstructed wavefronts have a slight curvature. This is caused by diffraction of the relatively small aperture. Fig. 3(c) is a reconstructed image when a glass plate of 5-mm thickness is inserted at 45° inclination to the transducer T_{d1} as shown in the schematic diagram. Horizontal fringes between the glass plate and the transducer (right side in the figure) are the results of superpositions of ultrasound reflected at the glass plate and the air-glycerol interface.

All the images in Fig. 4 are obtained by inserting a glass bead of 15-mm diameter in the pathway of the ultrasound as shown in the schematic diagram. The position of the light sheet is different for each reconstructed image. The shift of the position is done by slightly moving the cylindrical lens L_3 normal to the light sheet. The light sheets are shown by solid lines in the figure. Each letter corresponds to Fig. 4(a), (b), and (c), respectively. We can see a spherical wave emanating from the bead. The apparent curvatures of the spherical wavefronts in the reconstructed images become smaller as the distance of the light sheet from the bead center becomes larger.

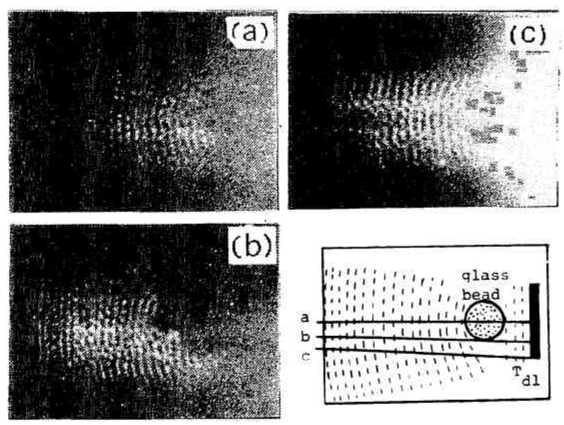

Fig. 4. Reconstructed images with glass bead inserted. In each figure, position of light sheet is slightly changed as shown.

IV. Conclusion

Some wavefronts of a 1-MHz ultrasound propagating in the interior of the glycerol are visualized by utilizing the holographic interferometry. This experiment demonstrates that three-dimensional wavefronts of an ultrasonic field can be visualized by simply varying the position of the light sheet. We can analyze the three-dimensional nature of wavefronts from these reconstructed interferograms and then evaluate transducers and acoustic lenses from the analysis.

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