ULTRASONIC IMAGING OF INTERNAL STRUCTURE BY BRAGG DIFFRACTION*

John Landry, John Powers, and *Glen Wade*
Department of Electrical Engineering
University of California
Santa Barbara, California 93106
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Results of experiments are described in which the technique of ultrasonic imaging by Bragg diffraction was used to observe internal detail in an aluminum plate and in a tropical fish. In addition, the extension of the Bragg technique to reflection and dark-field imaging is described.

A technique has previously been described which uses Bragg diffraction for producing optical images of ultrasonically illuminated objects.[1-3] This method has the convenience of real-time capability and is most suitable for imaging with acoustic energy whose wavelength is within one or two orders of magnitude of that of the interacting light. The method has been used with the light–sound interaction taking place in both liquids and solids, water being a suitable medium for frequencies below about 50 MHz. Above this frequency, the acoustic attenuation in water and other liquids is excessively high and it is then necessary to use a solid medium such as quartz.[4] In this letter, we describe the results of several experiments using the Bragg technique at 15 and 25 MHz with water as the imaging medium.

A diagram of the system used in our experiment is shown in Fig. 1. The acoustic cell, in which objects to be imaged are placed, is an aluminum box measuring 20 × 10 × 9.5 cm. There is a panel across the middle of the cell on which a 5 × 5-cm quartz transducer is mounted. This transducer has a fundamental frequency of 5 MHz but can be driven at odd harmonics of the fundamental. The final image resolution is directly proportional to the acoustic frequency so it is desirable to use the highest practical frequency. Since biological materials generally have very high attenuation for acoustic energy much above 15 MHz, we chose this frequency for experiments with such materials. For other objects, it was possible to use a frequency of 25 MHz and thus obtain significantly higher resolution.

Referring again to Fig. 1, the two spherical lenses expand the laser light to a collimated beam about 3 cm in diameter which is then converged to

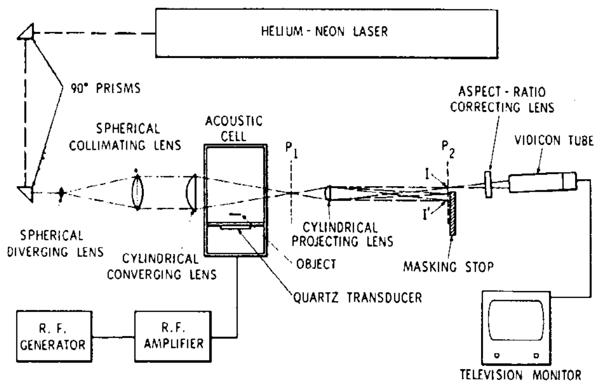

Fig. 1. Top view of the Bragg imaging system.

a vertical line (i.e., a line perpendicular to the plane of the paper) by a cylindrical lens. As this beam passes through the water in the acoustic cell, some of the light is Bragg-diffracted by the scattered ultrasonic waves and two images are produced at the plane P_1 (the focal plane of the undiffracted light) in the manner described in Ref. 1. While the imaging in the horizontal direction (and thus the resolution in that direction) depends on the angular selectivity of Bragg diffraction, that in the vertical direction is essentially a shadow of the sound beam cross section in the region of the light–sound interaction. For this reason, vertical resolution improves as an object is moved away from the transducer and toward the light beam, while the horizontal resolution is unchanged. As a consequence of this, the image shown as I in Fig. 1 provides better vertical resolution than I'. (Note that the cylindrical projecting lens reverses the images and thus I is the image formed by the light diffracted closest to the object.)

For the Bragg imaging, the magnification is given by the ratio of the light wavelength to the

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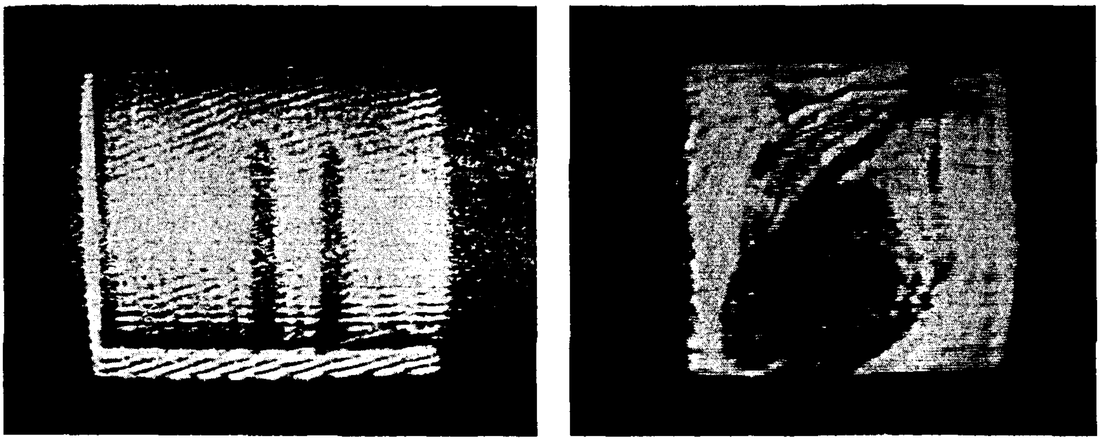

(a) (b)

Fig. 2. Images of internal structure: (a) holes in aluminum plate, (b) tropical fish (approximately life-size).

acoustic wavelength (about 1/100 for f = 25 MHz) but the shadow imaging has unity magnification. The aspect-ratio distortion resulting from this is corrected by the remaining lenses shown in the system. The projecting cylindrical lens has its axis oriented the same way as the converging lens and it projects the two images (and the undiffracted beam) to the plane P_2 with some desired magnification. The undiffracted beam and one of the images are removed at this plane by a masking stop. Any remaining error in aspect-ratio is corrected by the final cylindrical lens which has its axis at right angles to the others. The corrected image is focussed directly onto the photocathode of a 1-in. vidicon camera tube and then presented on a television monitor.

If a uniform plate of material having low acoustic attenuation is placed in the cell, certain orientations will be found where most of the incident acoustic energy is transmitted by the plate, and thus it appears transparent. If there are any acoustically absorbing or scattering centers within the material, they will then be visible on the screen.[3]

To demonstrate this effect we prepared a plate of 7.0-mm-thick aluminum, with two holes of 1.5 mm diam spaced 7.5 mm apart drilled into one of its edges. When the plate is placed in the cell, the image shown in Fig. 2(a) appears on the monitor. The outline of two sides of the plate are visible and the two holes show up clearly as dark silhouettes (the theoretical resolution for this experiment was about 0.3 mm). The method can be used to show the internal structure of biological objects as shown by Fig. 2(b). Here, we have placed a tropical fish of the "Silver Dollar" variety (*mylossoma argenteum*) in the acoustic beam. The fish is about 3.5 cm in length. As mentioned above, the acoustic frequency for this experiment was 15 MHz. Note that the backbone of the fish is visible and the fish's organs appear as dark areas on the screen. The acoustic energy density for this experiment was approximately 0.03 W/cm^2 which is much too low to cause any injury to the fish.[5]

Another experiment was tried in which the cell was rotated about a vertical axis to a position where no light was diffracted by the unscattered components of the sound. The result of this is that no bright background, corresponding to the acoustic beam cross section, appears on the screen. We then placed a glass microscope slide, prepared with masking tape letters on its surface, at the far end of the cell from the transducer. By orienting the slide in the proper way, the acoustic waves were reflected from its surface and back into the light beam at such an angle that diffraction did take place. Since the tape letters absorb the acoustic energy rather than reflect it, they appear as dark silhouettes on the bright background representing the reflected acoustic beam from the slide. (See Fig. 3.) This demonstrates the capability of the Bragg method for imaging by reflection.

Using the same orientation for the cell, when

Fig. 3. Glass slide imaged by reflection.

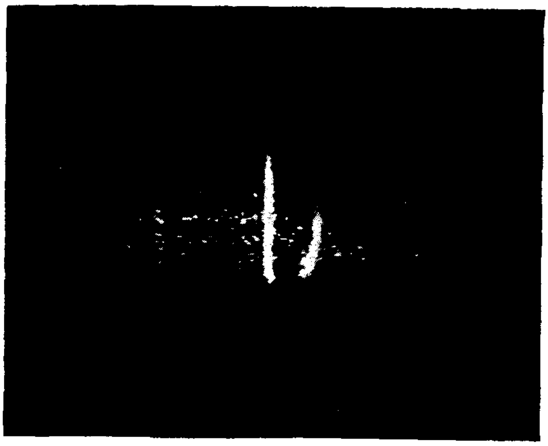

Fig. 4. Dark-field image of wire hook.

an object is placed in the sound beam in the usual location (i.e., as shown in Fig. 1) a bright outline of the object on a dark background appears on the screen. An example is shown in Fig. 4. Here the object is a hook made of copper wire having a diameter of 1.0 mm. The principle is similar to that of dark-field microscopy. The light–sound interaction occurs only with scattered acoustic waves resulting from high spatial frequencies in the object, thus edges of objects wider than the hook would be enhanced in their images. Since this method uses scattered sound only, shadow imaging in the vertical dimension does not take place with our system. Horizontally oriented features of the object do not scatter the sound into the appropriate angle for producing an image of those features. This fact explains the absence of the curved portion of the hook image in Fig. 4. A system using Bragg diffraction in both dimensions would allow two-dimensional dark-field imaging and thus could offer some advantage for shape recognition.

In view of the real-time capability and the good resolution properties of the Bragg imaging method, we believe that it offers considerable potential as a possible technique for both flaw detection and medical diagnostic applications.

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