

ACOUSTOGRAPHIC EVALUATION OF ULTRASONIC TRANSDUCERS

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INTRODUCTION

In order to have confidence in the nondestructive evaluation data generated by an ultrasonic system, it is important to establish the adequacy and reliability of the ultrasonic transducer employed in the system. This is usually accomplished by characterizing the electro-mechanical properties and the radiated acoustic field distribution of the transducer. The methodology for characterizing the electro-mechanical properties, including insertion loss, Q-factor, impulse and frequency spectrum, is well established and has been reported in the literature [1, 2]. Characterization of the acoustic field distribution involves determination of the beam diameter, propagation angle and axial and cross-sectional uniformity. The methods used for obtaining these field characteristics include the Schlieren [3], ball reflector [4] and hydrophone scanning [5]. Although these methods have been used effectively to characterize transducer fields, they do have some limitations. The Schlieren method requires elaborate optical set-ups and only yields the axial profile of the field distribution. The ball reflector and hydrophone methods are point-by-point scanning methods and therefore require complex scanning mechanisms and sophisticated electronic instrumentation for full characterization of the acoustic field. The latter two methods are also time-consuming since a large amount of data has to be collected for generating the axial and cross-sectional field distributions.

In this paper, we discuss the application of Acoustography [6] for evaluating the acoustic field characteristics of ultrasonic transducers. Acoustography offers some unique advantages over the above mentioned field characterization methods and offers the potential for enhancing the current state-of-the art of transducer characterization.

ACOUSTOGRAPHY

Acoustography, similar to radiography, uses an "acousto-optical" liquid crystal display to visualize ultrasound [7,8]. The physical mechanism by which the display converts ultrasound into visual images is based upon the birefringent properties of the liquid crystal material in the display. Initially, the liquid crystal molecules are parallel to each other, Figure 1. When the display is viewed under polarized light with crossed polarizer/analyzer, it shows a uniform dark field of view. When ultrasound interacts with the display, the orientation of the liquid crystal molecules changes. Due to the liquid crystal's birefringent properties, the reorientation is viewed as a brightness change in the field of view, Figure 2. The level of brightness depends upon the ultrasonic intensity level of the ultrasonic source, Figure 3.

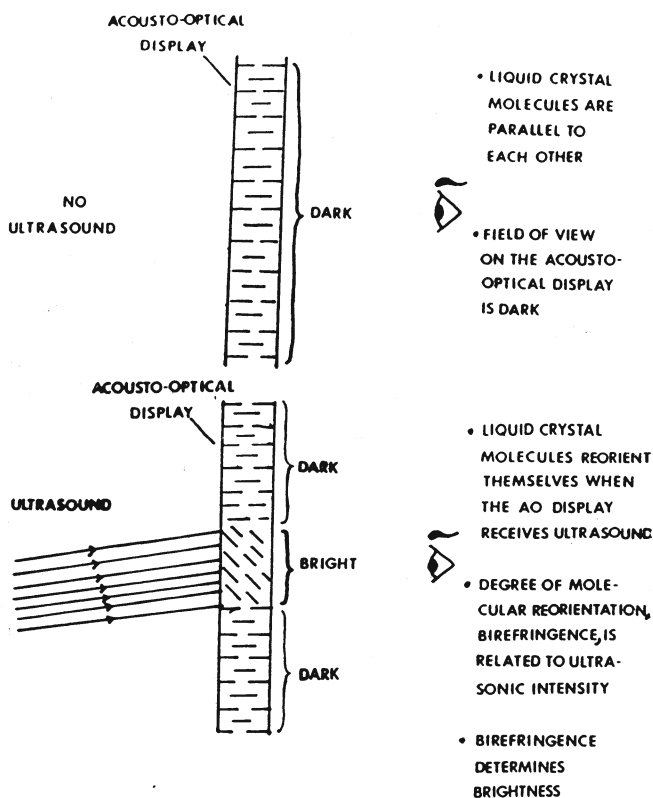


Fig.1 Ultrasonically Induced Reorientation of Liquid Crystal Molecules

The relation between ultrasonic intensity and the corresponding brightness level (gray scale) is expressed by an Acousto-Optical Transfer Curve (AOTC), Figure 4. This curve characterizes the display for acoustography in the same way an H&D curve characterizes the

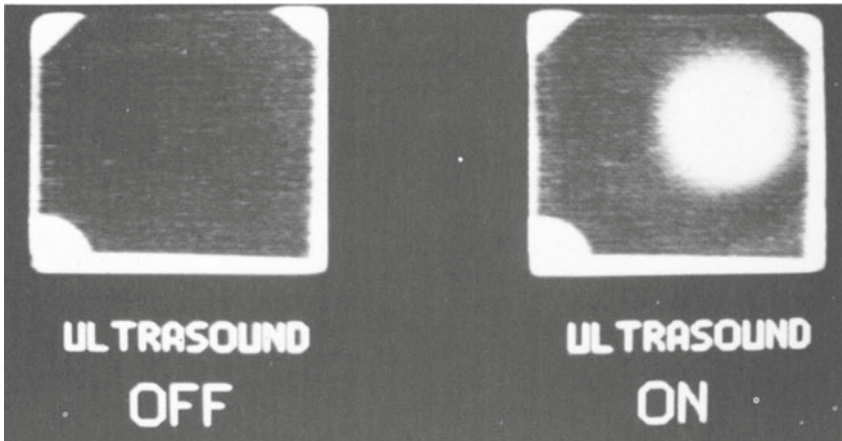


Fig.2 Field of View showing the Unexposed and Exposed Acousto-optical Display.

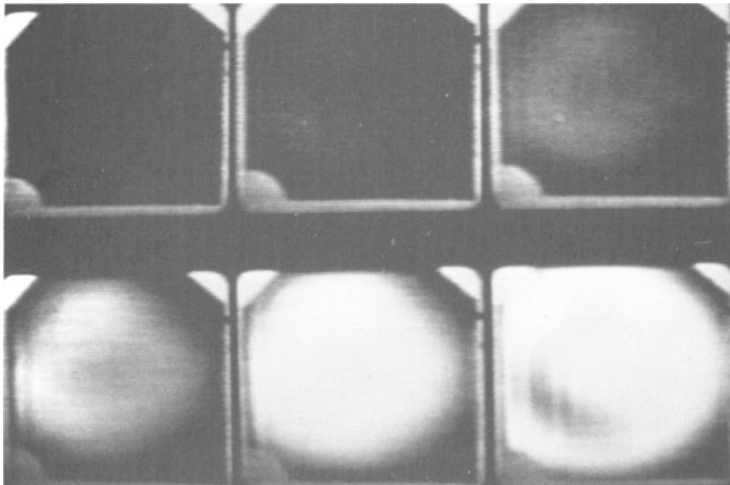


Figure 3 Brightness Level as a Function of Ultrasonic Intensity

radiographic film for radiography. It should be noted that beyond a certain ultrasonic intensity, the display exhibits colors corresponding to different intensity levels (color scale). This is due to the dependence of birefringence on the wavelength of light used to visualize the display. Because we use white light, the red, blue, green, etc. components are separated at different ultrasonic intensities. This separation enables visualization of ultrasonic images in color. The AOTC slope, colors, response times and dynamic range of the display determine its adequacy for acoustographing a given transducer, material or structure. It is therefore customary to characterize the display for these parameter before it is used for acoustographic studies.

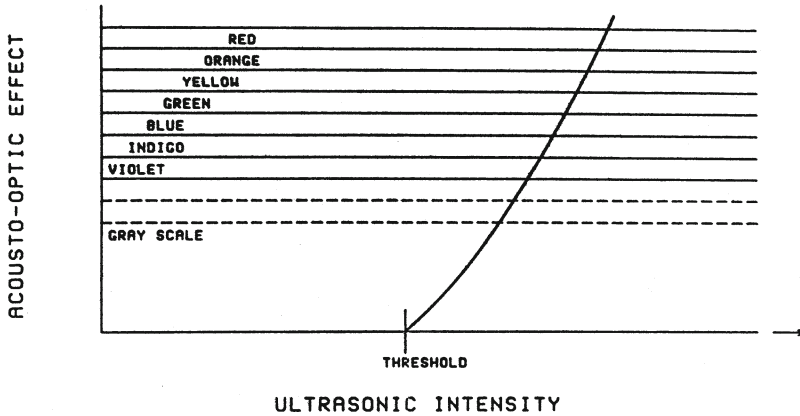


Fig.4 Acousto-optical Transfer Curve

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Figure 5 shows the acoustographic system utilized in this work. The test transducer and the acousto-optical display are suspended in an immersion tank filled with water. The transducer radiation axis is arranged to be 1 to 3 degrees off with respect to the display normal. The test transducer is positioned at various distances from the acousto-optical display to allow the display to intercept the ultrasonic beam at various points in the Fresnel and Fraunhofer zones. When the transducer is energized with a signal from the r.f. electronics, the image of the radiated field cross-section appears on the display. The video camera views the transducer field image on the display with the aid of polarizing optics and sends it as a video image to the Image Capture Board (ICB) and a TV monitor. The ICB digitizes the image for storage in the computer memory. The r.f. voltage across the transducer is measured using an Oscilloscope.

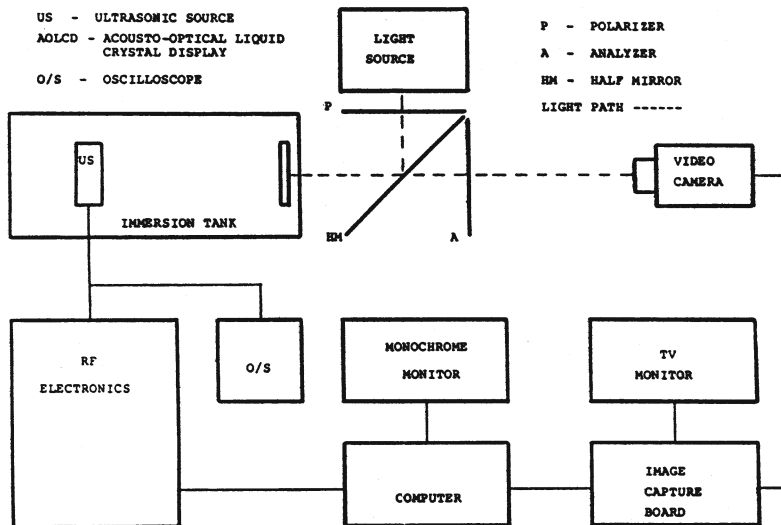


Fig. 5 The Acoustographic System

ACOUSTO-OPTICAL TRANSFER CURVE

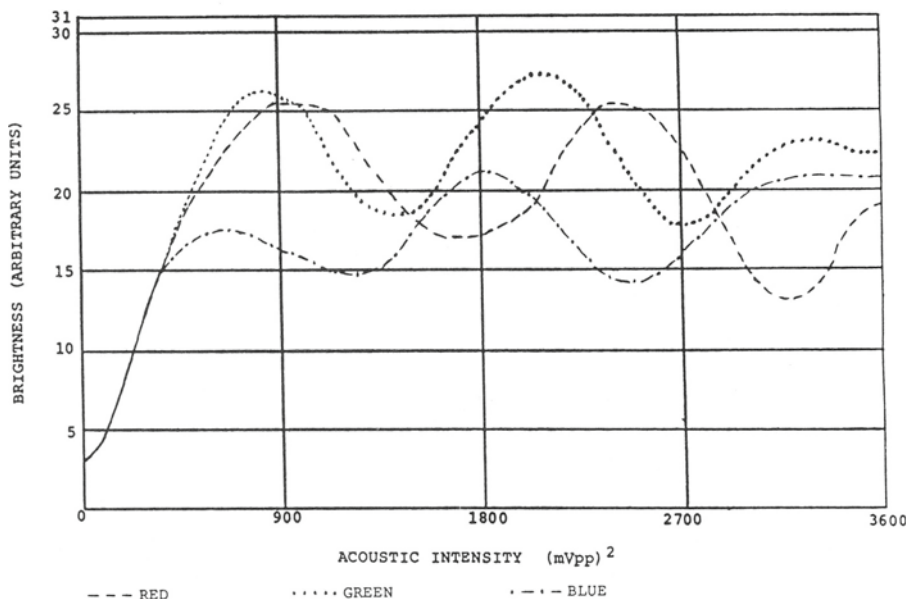


Fig. 6 Acousto-optical Transfer Curve of the 3.42 MHz Display

Figure 6 shows the acousto-optical transfer curve (AOTC) of a 3.42 MHz display used in the present work. The AOTC was determined by selecting a small area in the display's field of view and measuring the intensity of the primary color (red, green, blue) components as a function of ultrasonic intensity (mVpp^2). The AOTC exhibits a somewhat linear region at the lower range of acoustical intensities ($<400 \text{ mVpp}^2$). In this region, the red, green and blue components are nearly equal. Therefore, the display exhibits a gray scale in this region. At higher acoustical intensities, the magnitudes of the red, green and blue components vary sinusoidally. This is the color range where the color is determined by the relative intensities of the three primary colors. In the present work, transducer fields were visualized in the linear region of the display.

Figure 7 shows the variation of ultrasonic intensity along the radiation axis of a 1" (25.4 mm) diameter, disk-type piezo-electric transducer operated in water at 3.42 MHz. These results were calculated from well established theory [9] and show the familiar maxima and minima in the Fresnel zone, points A, B, C, D, and E. Point F corresponds to the transition between the Fresnel and the Fraunhofer zones. The acoustographically visualized cross-sectional field distributions at points A, B, C, D and E of a commercially purchased 1" dia., disk-type transducer operated at 3.42 MHz (CW) are shown in Figure 8. The agreement between the calculated distances and those determined acoustographically is good considering there is an error of $\pm 2 \text{ mm}$ in our distance measurements. Furthermore, we are not sure if the transducer radiating surface is exactly 1" in dia. The cross-sectional field distributions in the Fraunhofer zone of the transducer are shown in Figure 9. Note the familiar Gaussian distribution.

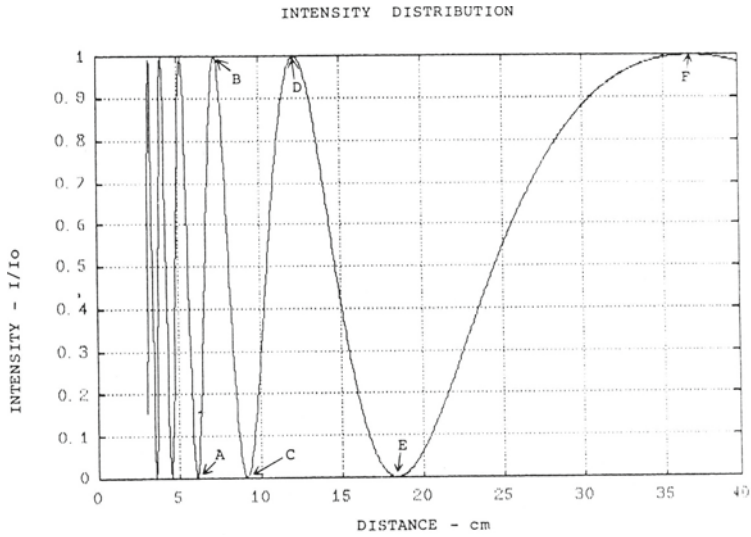


Fig. 7 Calculated Acoustic Intensity Variation along the Radiation Axis of a 1" Dia., Disk-type piezo-electric Transducer operated in H₂O at 3.42 MHz

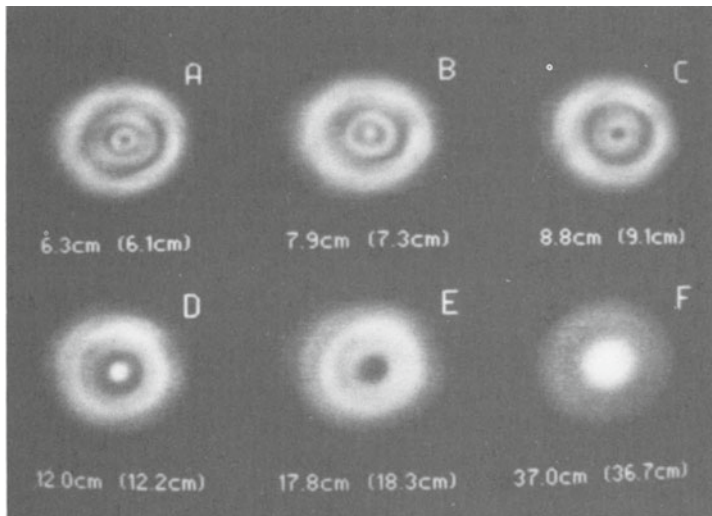


Fig. 8 Acoustographically Visualized Cross-sectional Field Distribution in the Fresnel Zone of a Commercially Purchased 1" Dia., disk-type piezo-electric Transducer operated in H₂O at 3.42 MHz; (-) shows calc. value

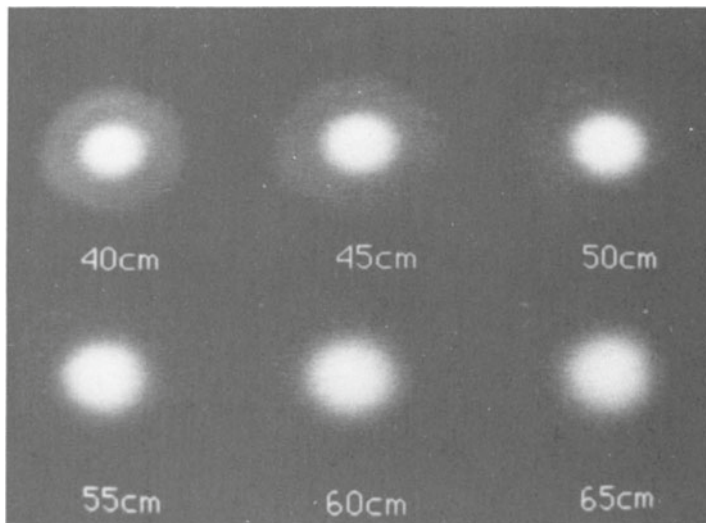


Fig. 9 Acoustographically Visualized cross-sectional Field Distribution in the Fraunhofer Zone of the Commercially Purchased 1" Dia., disk-type piezo-electric Transducer operated in H₂O at 3.42 MHz

Figure 10 shows the cross-sectional field distributions of a commercially purchased 1"x 1" (25.4mm x 25.4 mm) piezo-electric element. The transducer was operated in CW mode at 3.42 MHz.

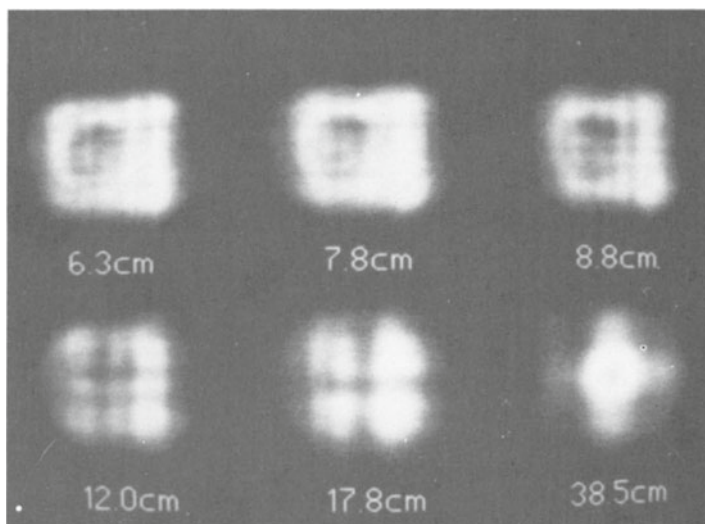


Fig. 10 Acoustographically Visualized Cross-sectional field Distribution of a Commercially Purchased 1"x 1" Dia., disk-type piezo-electric Transducer operated in H₂O at 3.42 MHz

DISCUSSION AND CONCLUSIONS

The application of acoustography for mapping acoustic fields of ultrasonic transducers is established. The cross-sectional field distribution data is generated within seconds, showing acoustography's potential as a high-speed transducer evaluation method. Work is in progress to develop software for generating the beam profile data from the cross-sectional field data. The display used in this work had a narrow frequency bandwidth (.5 MHz) and therefore is not suited for characterizing transducers with operating frequencies outside the display bandwidth. This problem can be overcome by designing individual displays with operating frequencies that are commensurate with the transducer frequencies. One other parameter of interest, particularly in the ultrasonic medical diagnosis, is the absolute ultrasonic power output (Watts/cm²) of the transducer. Acoustography offers a simple way of measuring acoustic power output of transducers [10]. In this method the acousto-optic effect, which is the basis on which liquid crystals visualize ultrasound, is nulled by a counteracting electrical field. The magnitude of the nulling electrical energy is proportional to the ultrasonic energy. By proper calibration, the nulling electric field can be used as a measure of the ultrasonic power. This work is also in progress and will be presented in due course.

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