A Novel, Rapid Method to Measure the Effective Aperture of Array Elements

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Abstract - Effective aperture is a commonly used measure of the amount of acoustic or electrical crosstalk between elements in ultrasonic arrays. It is also important to assess element-to-element uniformity and quality of the separation between the elements. This parameter is obtained from the beam profile obtained by pulsing each individual element with a known excitation function. The traditional method, using hydrophones, presents many challenges that are overcome by the proposed method.

Using a quantitative schlieren system, we imaged the acoustic burst from an array element. Automated processing allows determination of the average intensity over the burst at all angles (angular beam profile) and its width is used to determine the effective aperture for that element. Examples are presented for floating and purposefully coupled neighboring elements, and the results are in good agreement with those obtained with a hydrophone. The algorithm used for image analysis is also described.

CONVENTIONAL TECHNIQUES

To accurately determine array element parameters such as effective aperture, it is necessary to collect data over a curved path because of the small size of individual array elements. Typical hydrophone scanning systems are designed to translate hydrophones either at fixed linear increments over a flat plane, making it time consuming and tedious to collect data along non-linear paths. Moreover, hydrophones have limited angular response characteristics that prevent accurate off-axis measurements in the lateral direction. Scanning by having the hydrophone rotate around the source solves the angular response dependency, but adds complexity in alignment to ensure that the path is truly concentric and in the plane of radiation.

QUANTITATIVE SCHLIEREN SYSTEM

A quantitative ultrasound beam measurement system based on pulsed schlieren imaging offers many advantages for the measurement of effective aperture and other array element parameters. The system is shown in Figure 1 and described in detail elsewhere[1].

Studies have shown excellent agreement between quantitative schlieren and hydrophone measurements of ultrasound transducer output. [2,3]

The main advantage of the schlieren method is that data from the entire beam is collected at once, which allows for rapid determination of ultrasound field parameters. A second one is the simplicity of alignment, which allows taking data for all elements without recentering the equipment.

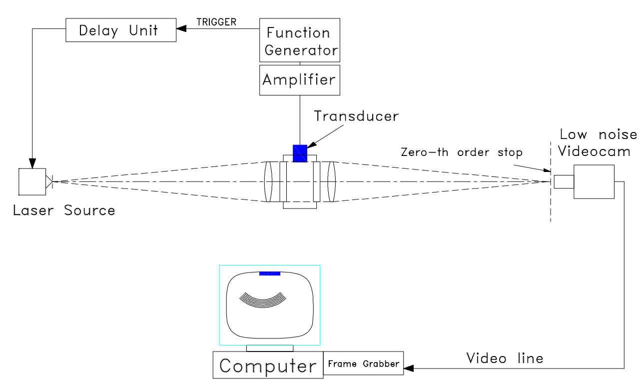

Figure 1. Diagram of the quantitative schlieren system used.

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EFFECTIVE APERTURE MEASUREMENT

Data Collection

A central element of a GE 3.5 MHz, 64 element phased array was chosen for these measurements. The transducer element was driven by a 12V, 3.4 MHz, 10 cycle pulse. The laser source was triggered through a delay circuit to capture the wave at 20 mm from the transducer surface. The resulting schlieren image is shown in Figure 2.

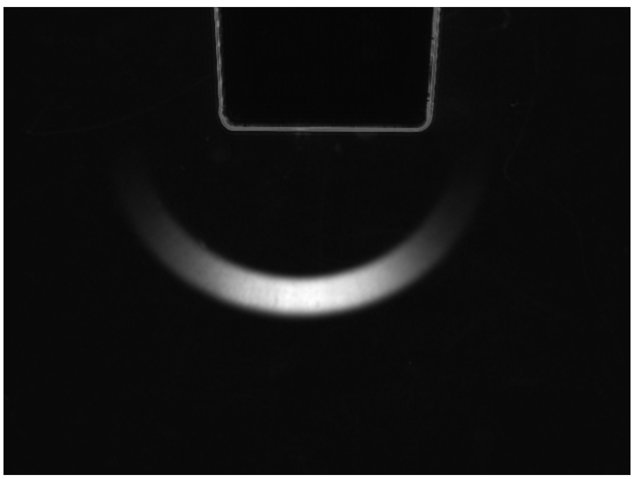

Figure 2. Image of single element radiation at 3.4MHz, 10 pulses.

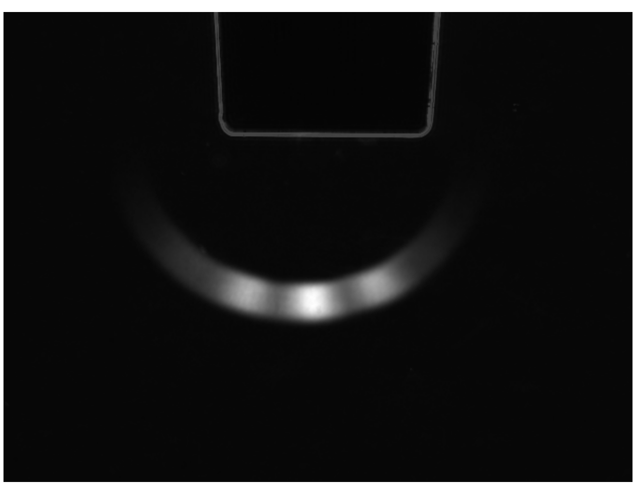

Figure 3. Image of single element with artificial cross-talk to neighboring elements.

To induce crosstalk, the two adjacent elements were connected to the signal through 1 KΩ resistors, and another schlieren visualization was made, as shown in Figure 3. The same driving signal and measurement range were used for this visualization.

Data Analysis

The automated analysis procedure is based on first locating the source of the wave, and then measuring the intensity radially from the source. The y-position of the active transducer element (y_s) is determined by the profile of the transducer, which is visible on the image. The horizontal position is obtained by calculating, for all points (x,y_s) the profile at +30° and -30°, the difference between the distances from (x,y_s) to the center of the pulse for each direction:

$$F(x, y_s) = \frac{\int rI(r, \vartheta = 30°)dr}{\int I(r, \vartheta = 30°)dr} - \frac{\int rI(r, \vartheta = -30°)dr}{\int I(r, \vartheta = -30°)dr}$$

The x-location x_s is found by interpolating $F(x,y_s)$ to meet the condition of equidistance to the source:

$$F(x_s, y_s) = 0$$

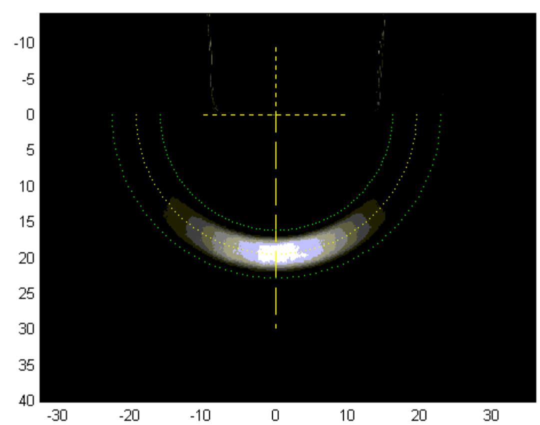

Figure 4. Image containing same data as Figure 2 after source location (origin) and range detection. Radial integration is subsequently performed from the origin.

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Once the source location (x_s, y_s) is known, the axial beam profile is generated by integrating the intensity along the radius for all angles between -90° and 90°. Figure 4 shows the image of the beam after the software has identified the location of the source and the range of radii for integration. The results of the radial integration is the beam profile:

$$I(\vartheta) = \frac{1}{(r_2 - r_1)} \int_{r_1}^{r_2} I(r, \vartheta) dr$$

where r_1 and r_2 are beyond the -20dB edges of the burst.

The effective aperture d is then estimated from the diffraction far-field fourier transform for a rectangular aperture[4] as

$$d = \frac{0.443\lambda}{\sin(\vartheta_h)}$$

where λ is the acoustic wavelength and ϑ_h is the half-angular width of the beam to 1/2 of its maximum value.

RESULTS

Figures 5 and 6 show the angular beam profiles obtained using this method, for the single element and the cross-talk enhanced case. In both cases the data are superimposed to the results of a hydrophone scan, obtained with a state of the art scanning system.

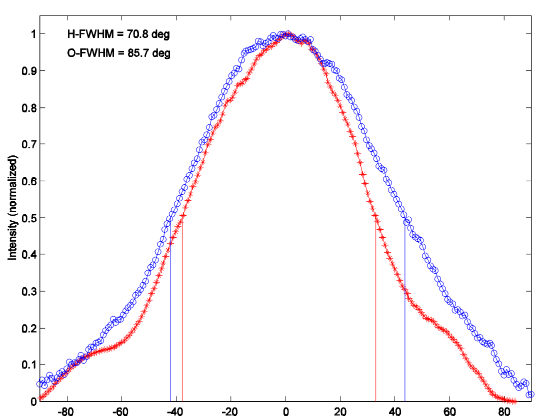

Figure 5. Beam profile for single element. Hydrophone (+) and optical (o) data.

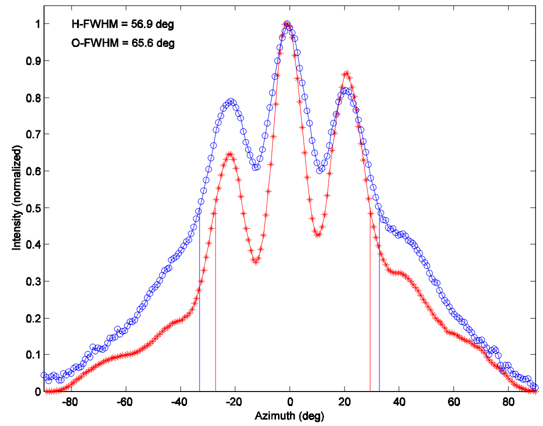

Figure 6. Beam profile for cross-coupled elements (see text). Hydrophone (+) and optical (o) data.

The effective aperture as measured by both methods in the two cases are as follows:

Eff. aperture:	Schlieren	Hydrophone
normal	290μ	340μ
w/ cross-talk	360μ	410μ

DISCUSSION

We observe a consistent difference between the two measurement methods, which needs further investigation. The only explanation we can find at this time is that possibly the transducer was rotated on its axis during the hydrophone measurement, making the beam plane intersect the hydrophone plane over a reduced region. This does not explain the deeper troughs in Figure 6, as there is a larger overlap among the radiation and detection planes in the forward direction.

Although the observed differences are not fully understood, the schlieren method provides fast and automated measurement of the effective aperture as a means of detecting cross-talk or other defects in the construction of ultrasonic arrays.

ACKNOWLEDGMENT

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