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THE EXPERIMENTAL DETERMINATION OF EFFECTIVE GEOMETRICAL PARAMETERS FOR A SPHERICAL CAP TRANSDUCER.

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Introduction

Focussed transducers are used in a variety of ultrasonic imaging situations to improve lateral resolution. The focussing achieved is usually computed on the basis of the geometrical parameters of the focussed element. It has been shown previously that the geometrical radius of a piezo-electric ceramic planar disc transducer is a poor predictor of the shape of the field actually radiated, while an effective (frequency dependent) radius, based on a single amplitude measurement, can be used to predict features of the phase distribution of the waves radiated (Chivers et al 1980, Chivers & Aindow 1980). The present paper reports on investigation into a similar analysis for focussed transducers. It may be expected that, with an extra degree of freedom, two effective parameters may be needed to describe the radiated field.

Theoretical considerations

The most widely accepted theory describing the acoustic field generated by a spherical cap ultrasonic transducer is that developed by O'Neil (1949). The excess acoustic pressure, p, at a point on the geometrical axis of the transducer, a distance x from its centre, is given by:

$$p = \rho\ c\ u_o\ P\ i\ \exp i\ (wt - km) \tag{1}$$

where $P = E \text{ Sin } k\ d/2$ (2)

$$E = 2\ /(1 - x/A) \tag{3}$$

$$d = \sqrt{[(x-h)^2 + a^2]} - x \tag{4}$$

and $m = (d+2x)/2$ (5)

where ρ is the density of the propagating medium, u_o is the velocity amplitude at the source, k is the wavenumber, a is the radius of the circular baffle round the transducer, h is the central depth of the shell and A is the centre of curvature. A typical distribution is shown in Figure 1.

The pressure modes (p = o) occur when the acoustic path difference, d, (Equation 4) is an integral number of wavelengths (i.e. $d = n\lambda$). The values of n are indicated on the diagram. The position of the i^{th} node, x_i, corresponding to n = i on the transducer side of the point of maximum pressure amplitude is related to the geometrical parameters a and h by:

$$\sqrt{[(x_i - h)^2 + a_i^2]} - x_i = i\lambda \tag{6}$$

The position of the true focus is given by:

$$x = A - 12A/(k^2h^2 + 12) \tag{7}$$

where A is the radius of curvature of the transducer.

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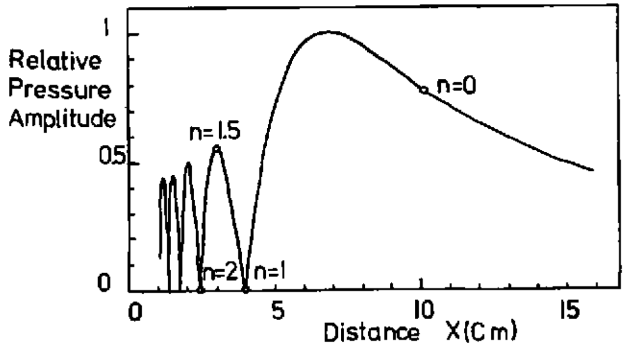

Figure 1. A typical axial pressure distribution of a focussed transducer.

The lateral distribution of acoustic pressure amplitude in the geometrical focal plane (x = A) is given by:

$$p = 2\, J_1\,(k\, a\, \mathrm{Sin}\, \theta)/k\, a\, \mathrm{Sin}\, \theta \tag{8}$$

where θ is the angle subtended by a point in the plane to the geometrical axis at the origin.

Experimental procedure and results

The axial pressure amplitude distribution of a spherical cap transducer having a = 7.5 mm, h = 0.282 mm, radius of curvature 100 mm and a nominal resonant frequency of 5 MHz was measured in a water tank at discrete frequencies in the range 3.5 - 15 MHz using a commercially available hydrophone with a 1 mm diameter element. The hydrophone was found to display a symmetrical amplitude directivity pattern over the whole frequency range. Tone bursts of typically 30 wavelengths in extent were used to excite the transducer. The experimentally determined positions of the true focus (the position of the point of maximum pressure amplitude) and the positions of the 1st two axial minima corresponding to n = 1 and n = 2 are shown in Figure 2 together with the calculated loci derived from equations (6) and (7).

The error bars represent the uncertainty in the measurement of the position of the true focus. It can be seen that the position of the true focus is found to be closer to the transducer than predicted. It appears that the experimental data agrees with the theory for the true focus only for frequencies up to 5 MHz. In a similar way the positions of the nodes are found to be closer to the transducer but agreement with the theoretical curve is not achieved at any frequency.

The lateral field distributions at the position of the geometrical focus

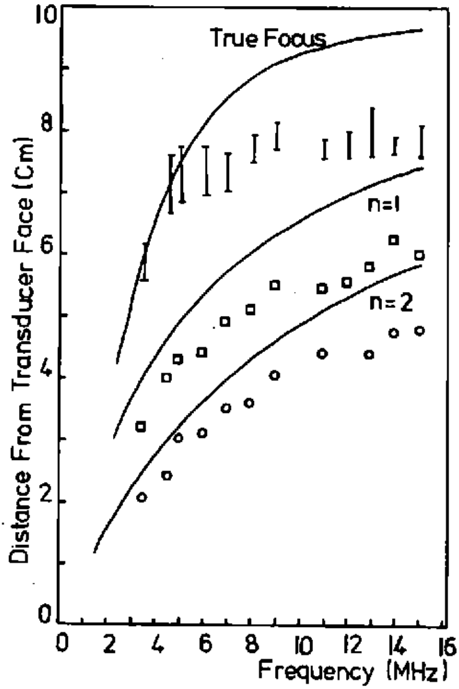

Figure 2. Comparison of experimental data with the theoretical loci for the true focus and the first two axial nodes (n=1,2) calculated using the nominal geometrical parameters of the focussed transducer (a=7.5 mm, h=0.282 mm).

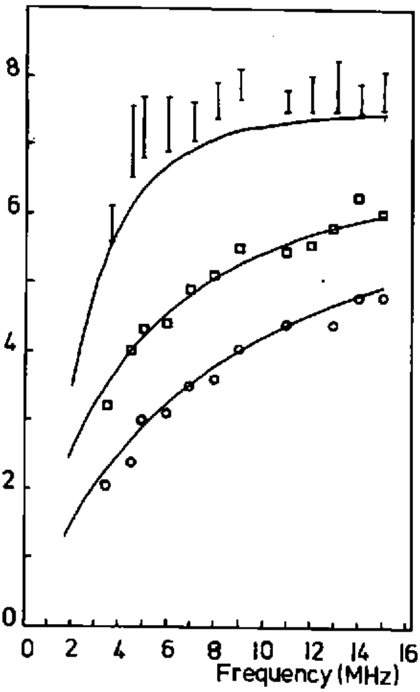

Figure 3. Loci of the true focus and first two axial nodes (n=1,2) calculated using an effective value for h of 0.37 mm and a = 7.5 mm.

were also determined and compared with the theoretical calculations based on Equation (8) from which it was concluded that the effective radius of the transducer, a_{EFF} was almost the same as the geometrical radius, a.

Analysis of results and discussion

Based on the equality (a_{EFF} = a) an effective value of h, h_{EFF}, was calculated from the position of the 1st node in the experimental distribution at one frequency and was subsequently used in equations (7) and (8) to generate the loci of the positions of the first two axial nodes and that of the true focus, which would best fit the experimental data over the whole frequency range. The results of these calculations are shown in Figure 3. The best value of h_{EFF} was found to be 0.37 mm which is about 30% greater than the nominal geometrical value. The fit here was purely subjective, a least squares fit would provide a more objective assessment but it was felt that the simple approach adopted here was sufficient to illustrate the existence of an effective value of h.

This approach is, however, somewhat inconsistent, in that, although it predicts the positions of the modes very well, to within ± 1 mm at most frequencies, it underestimates the position of the true focus by up to 5 mm.

Conclusion

A good first approximation to the acoustic field can be derived by calculating an effective value for h, which requires only one experimental measurement, the location of the axial position of the first node (n=1) on the transducer side of the true focus. The experiments were performed on a single transducer so similar measurements should be performed on other similar transducers to see if they behave in a similar way. The analysis has only been shown to hold over a limited axial range in the region of the focus and no conclusions can be drawn concerning the potential validity of the calculations outside this range. It is in any case very difficult to measure the field distribution in the near field of the transducer as there are problems in the interpretation of the hydrophone output.

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