ULTRASONIC POD MODEL VALIDATION AND DEVELOPMENT FOR FOCUSED PROBES

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INTRODUCTION

The growing need to quantify the ability to inspect a component at the design stage requires accurate and computationally efficient analytical models of the inspection process. In ultrasonics, a computer model has been developed which can simulate signals obtained from both crack-like and volumetric defects [1,2], and can estimate their probability of detection (POD) [3,4]. This model can be used to predict and optimize the inspection reliability with respect to the inspection system, the component design, and the critical defects.

The original POD model was extensively validated for planar probes. However, in many industrial ultrasonic testing applications, such as ultrasonic inspection of jet engine components, the use of focused probes is standard practice. Therefore, it was necessary to verify the applicability of the POD model for focused probes and to extend the model, if necessary.

An ultrasonic focused transducer is traditionally "defined" by three numbers stamped on its case: frequency, focal length, and diameter. However, the nominal values are often quite different from the actual values. This variability, depending on the particular testing application, could create experimental complications or result in misleading data. In addition, accurate probe characteristics are essential as input to the POD model to guarantee realistic model output. Therefore, the objective of this study was to develop a reliable method to determine the focal length and the diameter of ultrasonic focused transducers, and to estimate the system response (efficiency) of an ultrasonic instrument equipped with a focused probe.

Characterization of focused probes

The method involved obtaining normal incidence reflected RF waveforms from a flat surface at a number of water path distances and comparing the frequency components of these signals to predictions from an analytical model [5].

Two transducers, A and B with nominal values of 3" focal length, 3/8" diameter and 10 MHz center frequency, were tested. The water path Z_0 was varied from 2" to 8". The reflected signals were digitized and their frequency components were obtained from their Fourier spectra. The same frequency components were simulated by computer [5]. The computer simulation was repeated several times with different values for diameter and focal length of the test probe each time. Computer generated and experimental data were compared until the best agreement between the two was obtained. Comparisons between theoretical and experimental results for transducers A and B are shown in Fig. 1. Theoretical and experimental data were both scaled to have unit amplitude. The agreement for both probes is very good for all depths considered. For probe A, the best results were obtained using the manufacturer's specifications (3" focal length, and 3/8" diameter). However, for probe B the computer simulation predicted a discrepancy of over 60% from the probe's nominal focal length (4.9" estimated focal length compared to 3" nominal).

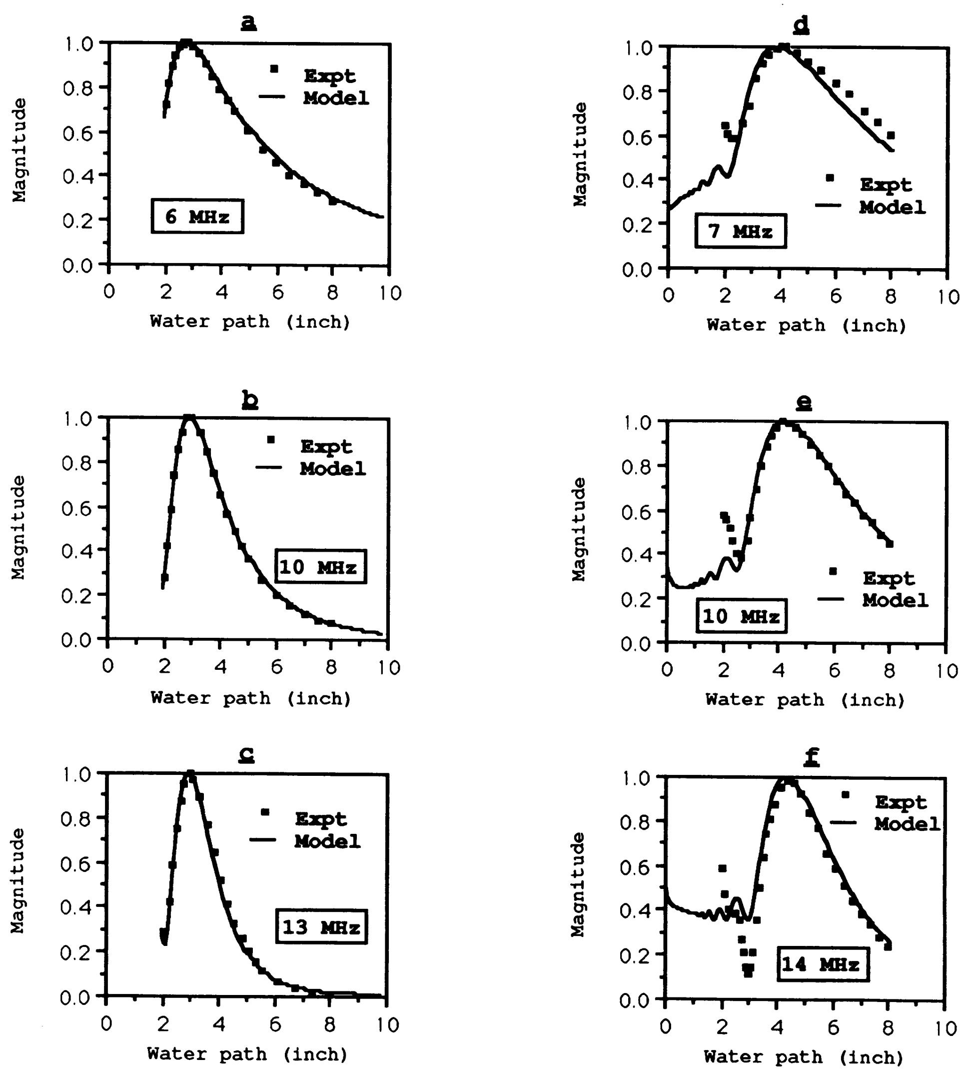

Fig. 1. Comparison between theoretical and experimental data for characterization of focused probes A and B.
(a,b,c) Probe A, frequency components 6,10, and 13 MHz.
(d,e,f) Probe B, frequency components 7,10,and 14 MHz.

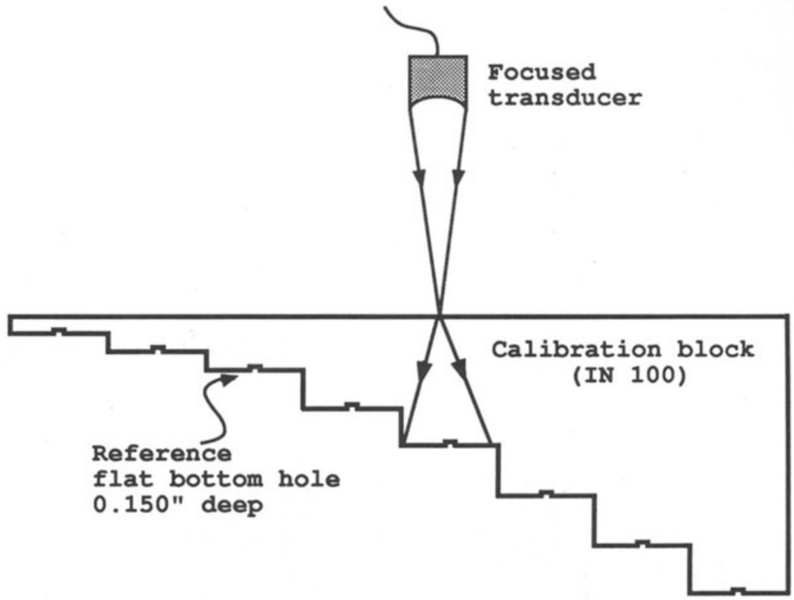

Fig. 2. Measurement geometry for validation of focused probes and calibration of measurement model.

Model validation

To validate the technique for focused probes and to calibrate the measurement model [1] a calibration block of IN100 [6] containing #1 flat bottom holes (1/64" diam.) at depths of .050", .100", .150", .500", 1.00", 1.50", 2.00", and 2.50" was used. The measurement geometry is illustrated in Fig. 2. With the transducer focused on the front surface, a reference waveform from a flat bottom hole at a certain depth was measured.

Using the measurement model

$$\delta\Gamma_F = \beta(TCP)^2\frac{2A\rho_1 V_b}{jka^2\rho_o V_o} \qquad (1)$$

where:

$\delta\Gamma_F$ is flaw signal,
β is ultrasonic system response,
T is interface transmission coefficient,
C is diffraction/focusing term (beam model),
P is propagation (phase and attenuation) term,
A is scattering amplitude of the flaw,
a is radius of the transducer
k is the wave number,
ρ_o and ρ_1 are fluid and solid densities,
V_o and V_b are fluid and solid wave velocities.

The overall ultrasonic system efficiency, β was then deconvolved as

$$\beta = \frac{\delta\Gamma_F(jka^2\rho_o V_o)}{(TCP)^2 2A\rho_1 V_b}. \qquad (2)$$

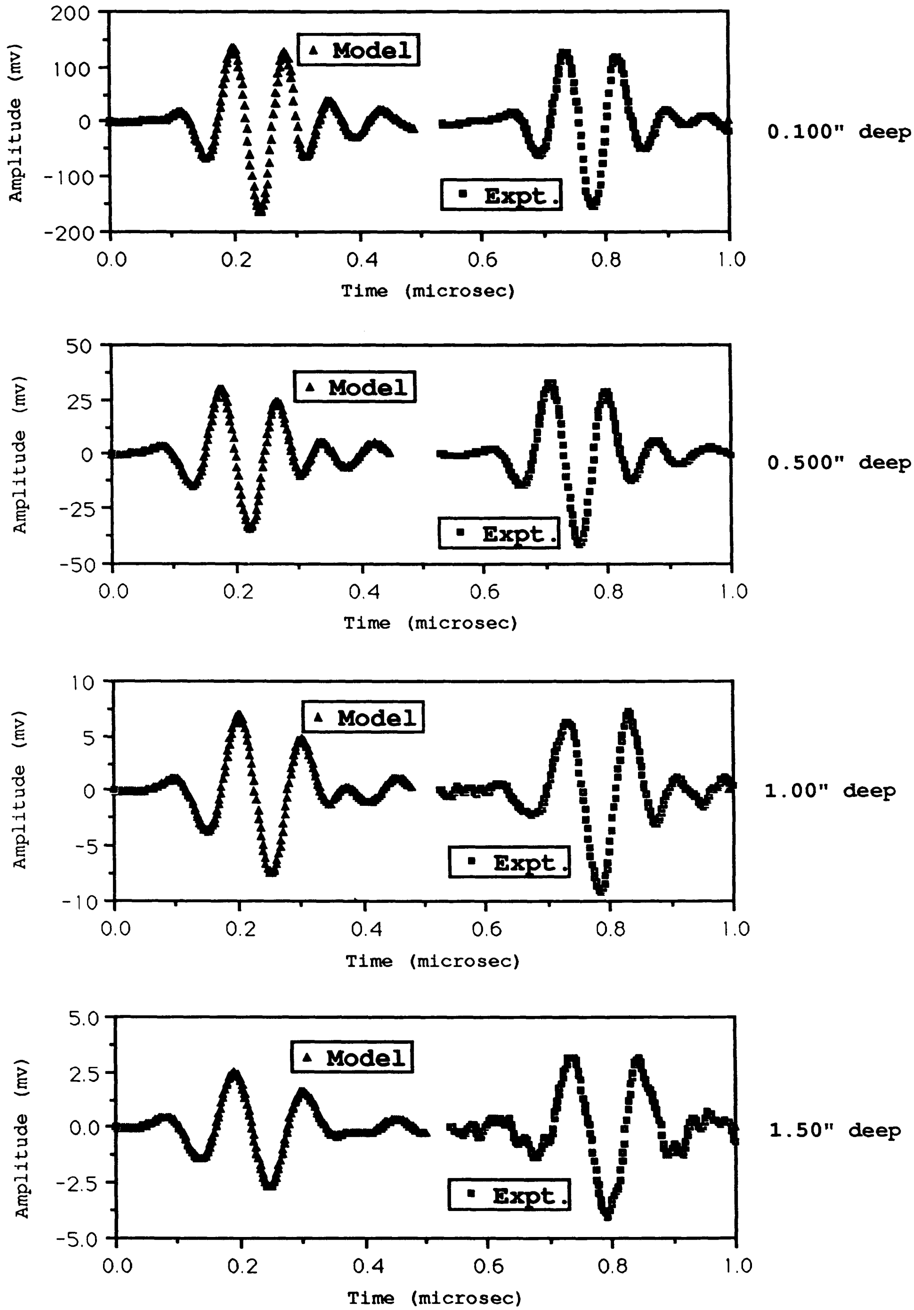

Fig. 3. Comparison between theoretical and experimental data in calibration the measurement model and validation the technique for probe A, using flat bottom holes in IN100 calibration block at various depths.

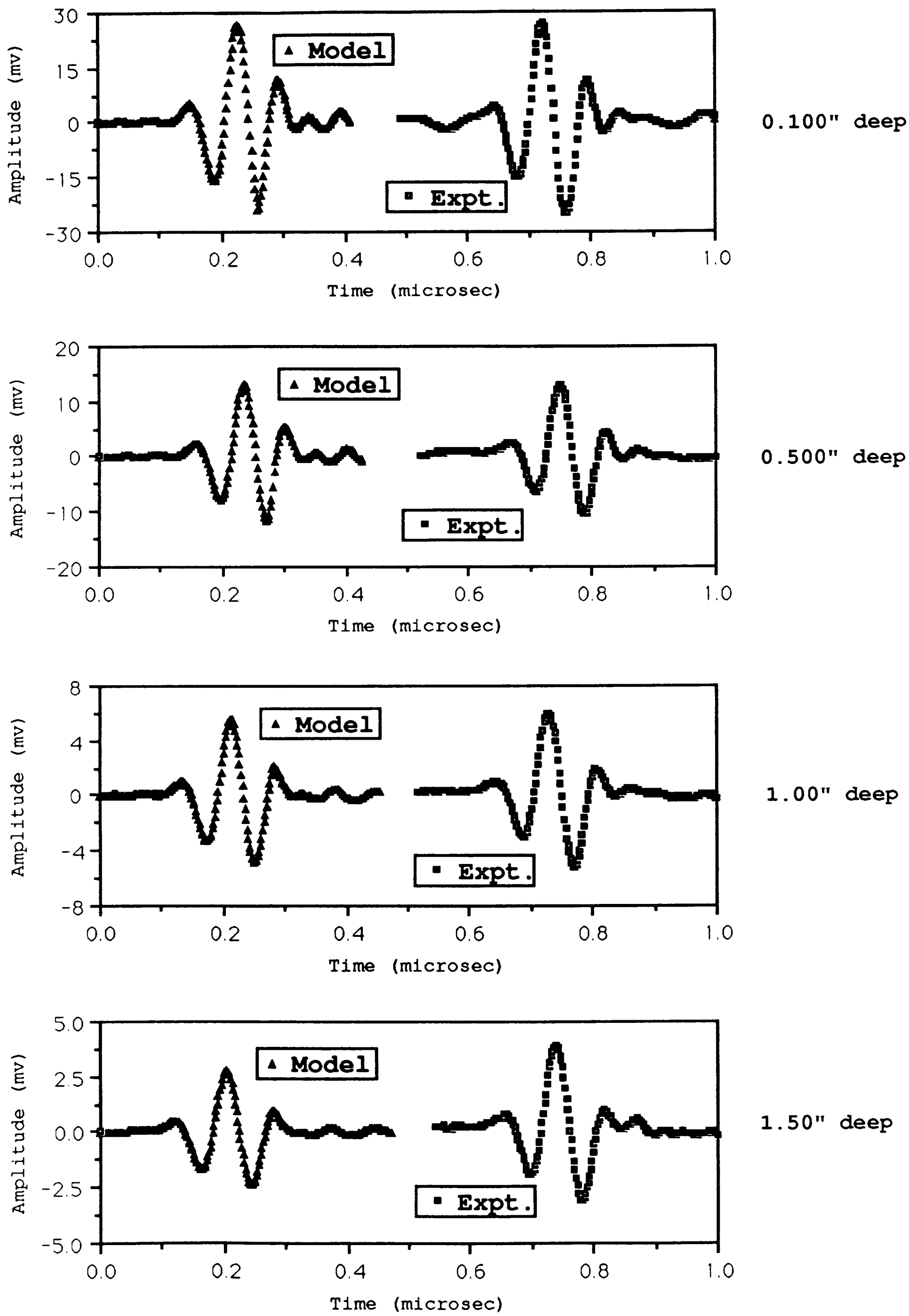

Fig. 4. Comparison between theoretical and experimental data in calibration the measurement model and validation the technique for probe B, using flat bottom holes in IN100 calibration block at various depths.

Using this reference β, waveforms from other flat bottom holes at various depths were simulated using equation 1. Figures 3 and 4 show the results of this calibration procedure for both transducers A and B. In both cases, the reference β was obtained using the signal from .150" deep flat bottom hole as the reference waveform. Signals from several other flat bottom holes in the calibration block were simulated using the reference β. Attenuation of IN100 in the model validation experiments was neglected due to its negligible magnitude when estimated from experimental measurements [1]. The scattering amplitude for flat bottom holes, A, was approximated by Kirchhoff's approximation [7] which reduces to

$$A = i\frac{K_L a^2}{2} \tag{3}$$

for normal L-wave incidence. Here K_L is the wave number and a is the radius of the flat bottom hole.

Experiments were performed to validate the model for different materials and various types of defects. Figure 5 shows the results of simulating a waveform from a #5 flat bottom hole (5/64" diam.), 0.5" deep in aluminum. The reference signal was obtained from an identical flat bottom hole in steel and Fig. 6 is the result of simulating a signal from a spherical void (bubble), .183" in diam., 1/8" deep in a planar fused quartz sample. A #1, flat bottom hole 0.15" deep in IN100 was used as the reference waveform. Probe A was used as the testing probe for both of the above experiments. In both cases, the agreement between the data and the simulated waveforms is excellent.

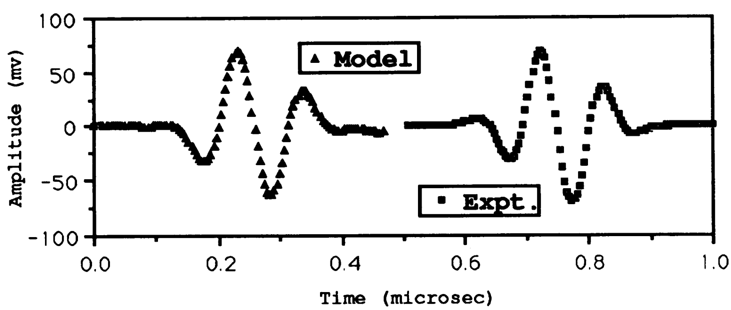

Fig. 5. Simulating a flaw signal from a void (.183") in fused quartz using a #1 flat bottom hole in IN100 as reference.

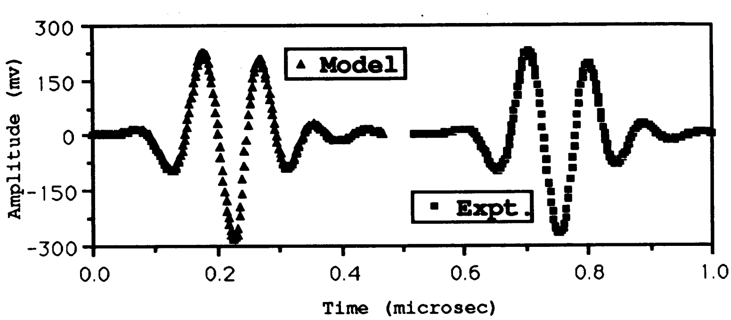

Fig. 6. Simulating a flaw signal from a #5 flat bottom hole in aluminum using the same size flat bottom hole in steel as reference.

SUMMARY

A method for estimating the effective diameter and focal length of a focussed ultrasonic piston transducer was examined. This technique extracts these parameters from a best fit of measured reflectivity from a flat surface to a computer model of this same phenomenon. The method had good sensitivity to both parameters. The resulting probe characteristics were used as input to a computer model of probability of detection of defects. The output results of this model, which consisted of simulated RF waveforms from flaws, were compared to experimental signals. The agreement was excellent. Further work is being pursued to develop a less computationally intensive method for probe characterization by examining the ultrasonic system response, or efficiency, obtained from a series of flat-bottomed holes at various depths below a planar surface. Preliminary results are very favorable. These methods provide the characteristics of focused transducers with the precision needed for accurate simulations of waveforms using a computer POD model. Moreover, the technique can be used to measure focused probe parameters in any practical application where precise characterization of a transducer's diameter and focal length are required.

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