ULTRASONIC FIELD OF A TRANSDUCER BEHIND A PLANE FLUID-SOLID INTERFACE

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INTRODUCTION

Ultrasonic echography is one of the methods which are more and more used for non destructive evaluation of materials, according to the requirements of the users who are often increasingly concerned by quantitative evaluation of defects. This requires a better knowledge of the measurement system, as well as of the ultrasonic field generated by the transducer inside of the material and this has led us to develop methods for the calculation of this field. We present a method for the determination of the ultrasonic field in a solid medium separated by a fluid-solid plane interface, from the knowledge, by modelization or by measures, of the field in a plane of the fluid medium. The method is based upon a decomposition by a plane waves obtained by spatial Fourier Transform, which permits a simple use of the SNELL-DESCARTES refraction laws at the interface. The method has shown quite good agreement with experimental results. Moreover, this method has permit us to predict undesirable effects in the case of oblique incident beams.

NUMERICAL METHOD

The pressure or the displacement of an harmonic wave is supposed known in a plane (the front face of the transducer for instance). This acoustic field is decomposed in plane waves by a spatial two-dimensional FOURIER transform. Then, it is easy to calculate the propagation of the waves in one medium and the transmission and reflection at a plane interface separating any two media by means of the SNELL-DESCARTES laws. Fig.1 presents the geometry of the problem. The Fourier Transform is performed by a FFT algorithm which requires a sampling with a constant step. After the propagation (between two non parallel planes) or the transmission through the interface, the sampling is no more evenly distributed. It is necessary to interpolate between the samples before performing the inverse FOURIER transform which gives the results. The method |1| permits to calculate the acoustic field in a plane set anywhere in the space, and in a solid for both longitudinal waves and shear waves. The longitudinal waves have been represented by the scalar potential and the shear waves by the vector potential. The vector potentials of each plane wave are not

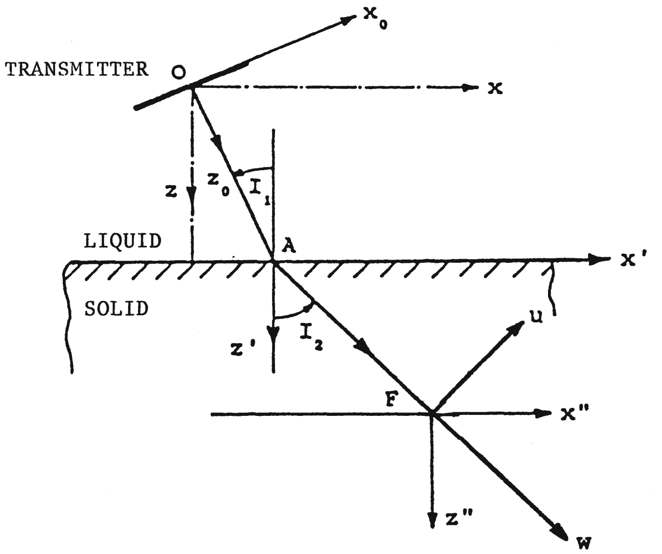


Fig. 1. Problem geometry

colinear and the inverse FOURIER transform is performed on each component of this vector.

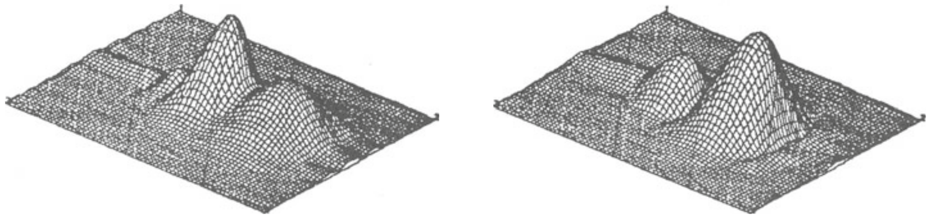
The advantages of this method are :

- there is no approximation if the interface is plane,
- the geometry may be two or three-dimensional,
- the entries may be either data coming from theoretical model (piston model, gaussian model, ...) or data coming from experimental measurements |2|.

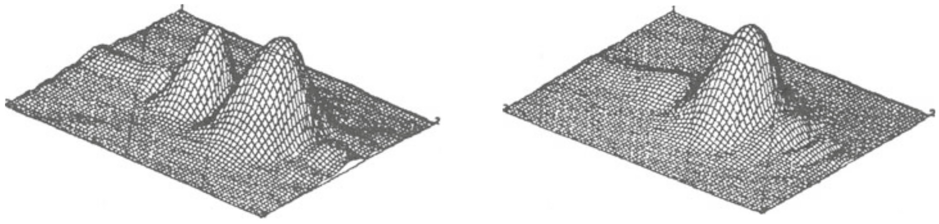
RESULTS

This method has been used for the calculation, in the case of tridimensional geometry, of the reflected field in the vicinity of Rayleigh angle. The effects of beam splitting commonly described in the literature are very pointed out and a strict comparison with results, either theoretical or measured from |3|, shows a very good agreement.

A beam splitting effect has been pointed out for shear waves transmitted in a solid when the incident beam angle is close to the longitudinal waves critical angle. This phenomenon can be seen on Fig. 2 which shows the spatial evolution, in an interface parallel plane, of the vector potential module (shear waves) for different incidence angles. The incident beam has a Gaussian profile; it is reflected by a plane interface between water and aluminum alloy. We observe a beam splitting clearly visible on Figs. 2a, 2b and 2c as well as secondary lobes less important (the critical angle in this case is 13.46 deg.). The minimum between the two principal lobes can be explained by the annulation of transmission coefficient for shear waves at the longitudinal critical angle. Beyond 16 deg., this effect decreases and the SNELL-DESCARTES refraction laws are valid for the whole beam.



a) I_1 = 10°   c) I_1 = 13.46°



b) I_1 = 12°   d) I_1 = 16°

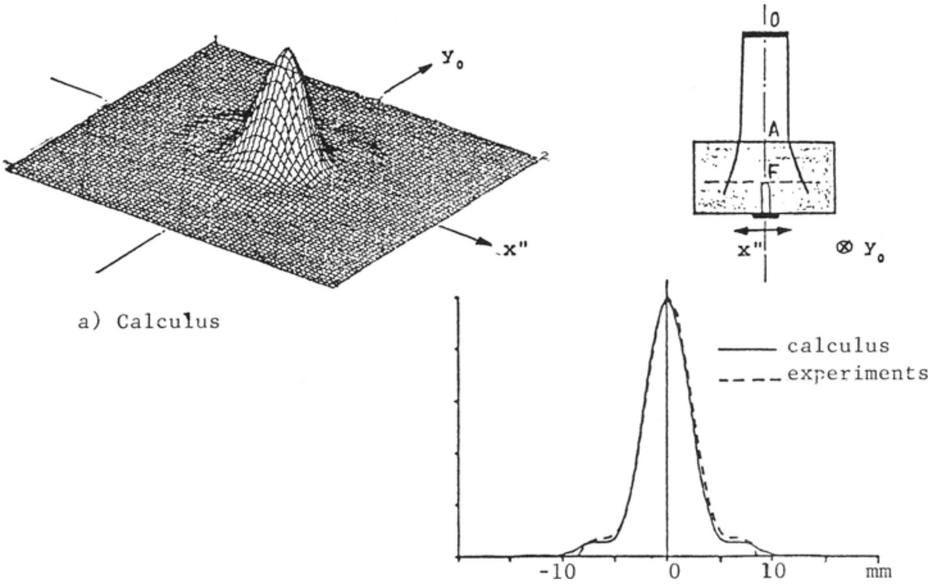
Fig. 2. Spatial distribution of the vector potential module (shear waves) transmitted into aluminium alloy for different incidences on both sides of longitudinal critical incidence

COMPARISON WITH EXPERIMENTAL RESULTS

Experiments have been performed in order to permit a comparison with the numerical model. An echographic method has been used |1| on semi-spherical targets created on aluminium alloy samples. The transducer is fixed, excited in transient mode, the echographic signal is observed at a single frequency after a FOURIER transform. The piece is moved to explore the acoustical field in a plane parallel to the interface. The transducers used are 5 MHz nominal frequency and the results are presented for this frequency. For the numerical results compared with experiments, we supposed than the front plane vibrates in piston mode.

Plane transducer

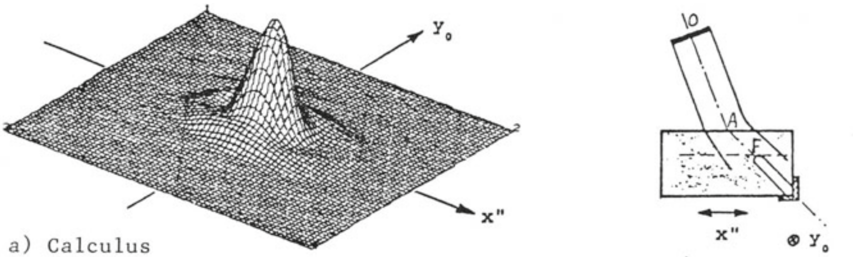
Figures 3 and 4 present the numerical and experimental results of the acoustic field of a plane transducer (ϕ = 12.7mm, υ = 5MHz) at normal incidence (longitudinal waves) and oblique incidence (shear waves) in an aluminium alloy sample (OA = 6cm, AF - 3cm). The numerical result obtained in normal incidence is in perfect agreement with experiment (Fig. 3b). For the oblique incidence, the agreement is excellent for a section pendicular by respect of incident plane (along $0''y_o$) and good enough for a section parallel by respect of incident plane (along $0''x''$). The small difference noticed for the secondary lobes might be explained by the fact that the piston model is not quite adapted to the considered transducer.



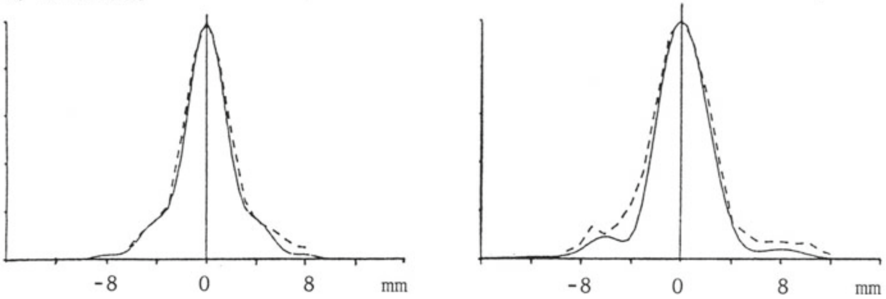
a) Calculus

b) Radial section

Fig. 3. Acoustic field distribution in aluminium alloy (longitudinal waves) for I_1 = 0 deg., 0A = 6cm and AF = 3cm



a) Calculus



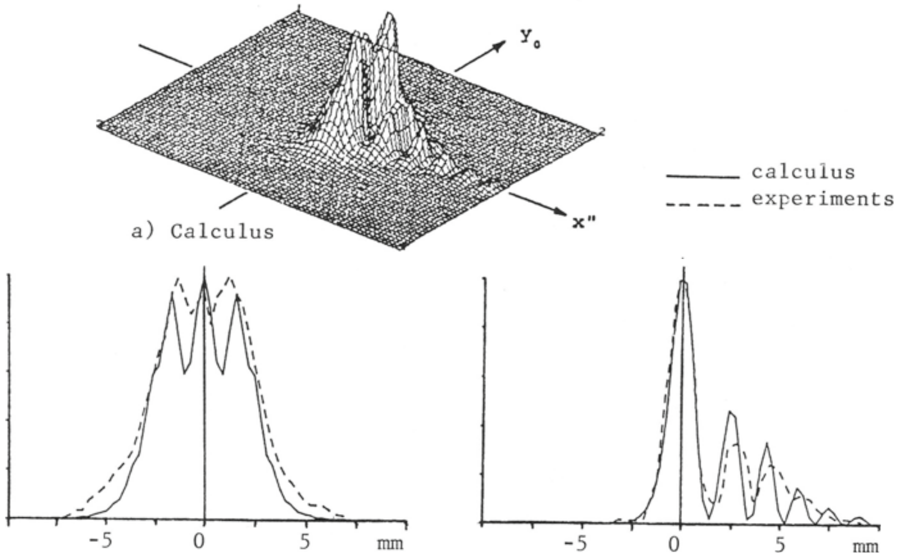
b) Section along y_o

c) Section along x''

Fig. 4. Acoustic field distribution in aluminium alloy (shear waves) for I_1 = 20 deg., 0A = 6cm and AF = 3cm

Focused transducer

Figure 5 presents the results for the acoustic field of a focused transducer (ϕ = 25.4mm, υ = 5MHz, f = 90mm) at a 20 deg. incidence. The geometrical configuration is the same as previously and is shown by Fig. 4. The theoretical and experimental results (Fig. 5b and 5c) are on the whole in good agreement. They give approximately the same dimensions of acoustic field along the two directions: 5.7mm along $\overrightarrow{O''y_0}$ and 1.4mm along $\overrightarrow{Ox''}$ and point out the same defocusing effects (widening of the beam and very important secondary lobes). The defocusing phenomenum can be explained by the geometrical acoustics theory (geometrical aberration of non-centered systems), and it is possible to correct partially this aberration for a given incidence by a lens with variable in azimuth curvature radius (for example torical lens).



b) Section along y_o

c) Section along x"

Fig. 5. Acoustic field distribution (shear waves) near the focal plane for I_1 = 20 deg., OA = 42mm and AF = 9mm

Figure 6 presents plane projections (contours) of the transmitted field for several distances AF (AF being the acoustical axis in the solid medium) as well in interface parallel planes. It is possible to observe on this figure, a strong asymetry of the beam, variable with the depth.

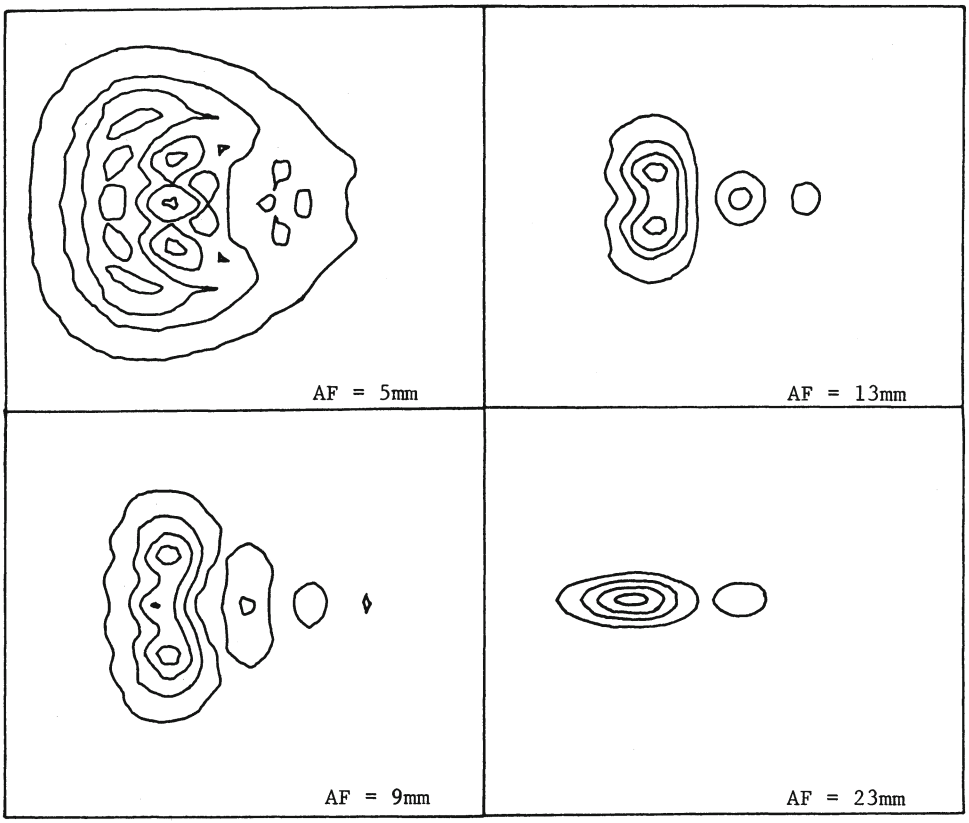


Fig. 6. Contour curves for acoustic field at different depth (Focused transducer, I_1 = 20 deg., OA = 42mm)

CONCLUSION

We have developed a numerical model which enables us to predict the acoustic field of a transducer in presence of a plane fluid-solid interface and this either in the fluid or in the solid for longitudinal and shear waves. This model has permitted to point out some important physical phenomena as the splitting of shear waves beam in solid when the incidence is in the vicinity of longitudinal critical angle, and the defocusing at non perpendicular incidence of beam of a spherically focused transducer. These results have been experimentally confirmed with a satifying accuracy on several examples.

ACKNOWLEDGEMENT

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