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Lamb waves generation in plates using glued piezoceramics

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In this work, Lamb waves have been generated in a thin aluminum plate by bonding a piezoceramic actuator onto the plate. The acoustic pressure immediately above the plate was measured by a needle hydrophone, coupled to the plate through a thin oil layer, across several centimeters. Use of a 2D FFT algorithm then provides the dispersion curves which compare well to the analytical solution calculated using the dispersion equation.
Next, the Lamb modes were selectively reinforced or cancelled by bonding another piezoceramic to the plate at an appropriate location. If the second actuator is excited in phase with the first one the symmetric mode, S0, can be reinforced whereas the antisymmetric mode, A0, is partially cancelled. If the two actuators are excited out of phase, the A0 mode is then enhanced respect to the S0 mode.

Keywords: Lamb Waves, piezoceramic, dispersion curves, NDT.

Generación de ondas de Lamb en estructuras tipo placa mediante cerámicas piezoeléctricas.

En este trabajo se han utilizado cerámicas piezoeléctricas para generar ondas de Lamb en estructuras tipo placa. Se midió la presión acústica a lo largo de unos centímetros de la placa mediante un hidrófono acoplado a ésta mediante una fina capa de aceite. Aplicando a esta información la trasformada bidimensional de Fourier se obtuvieron las curvas de dispersión experimentales y se compararon con las obtenidas teóricamente.
A continuación, los modos de Lamb se reforzaron o cancelaron pegando otra cerámica en la placa en la posición adecuada. Al excitar la segunda cerámica en fase con la primera amplificamos el modo simétrico, S0, mientras que el modo antisimétrico, A0, se ve parcialmente cancelado. Excitando las dos cerámicas en contrafase, reforzamos el modo antisimétrico, A0, respecto del simétrico, S0.

Palabras clave: Ondas de Lamb, cerámica piezoeléctrica, curvas de dispersión, END.

1. INTRODUCTION

Among the various sensors available for damage detection, piezoelectric materials (1,2) - piezoceramics - are particularly attractive as long as they can act simultaneously as transmitters and receivers. These sensors can be bonded or embedded on the structure to be analyzed. Its reduced thickness, low weight and low cost make them very useful when designing an integrated damage monitoring system. The development of a NDE system using Lamb waves requires the use of these piezoceramics. Lamb waves are guided waves that exist in thin wall structures with free boundaries. For a plate having a thickness of the order of a wavelength or so, surface Rayleigh waves can degenerate into Lamb waves (3). They are commonly used in the field of Non Destructive Testing (NDT) for defect location. Their capacity to propagate along plates over long distances with little attenuation make them an attractive option. However, because they are dispersive, multiple modes can be excited for a given frequency making defect identification difficult (4). Techniques to selectively filter individual Lamb modes will greatly enhance their utility in NDT.

2. EXPERIMENTAL PROCEDURE

PZ 27, 4 MHz (Ferroperm) piezoceramic actuators were chosen for the present research due to their high force output at relatively low voltages, and their good response qualities at both low and high frequencies. One piezoceramic, 7x7x0.5mm, was placed at the centre of an aluminum plate 1200x1200x1.1 mm - 2024-T3 Clad aluminum - to generate an omnidirectional Lamb wave. The piezoceramic was glued on the plate using an instant bonding cyanoacrylate adhesive. A small drop of adhesive was placed on the plate and then the piezoceramic was glued on by pressing firmly for a few seconds. Figure 1 shows a schematic diagram of the ceramic position on the aluminum plate.

A 5052 Panametrics Pulser-Receiver was used to generate the input signal. The acoustic pressure above the plate was measured across several centimeters with a needle hydrophone - Medisonics, UK - coupled to the plate with a thin layer of baby oil. The hydrophone displacement was controlled by a 3D computerized displacement system. The measured signals were then digitized with a Tektronix TDS 220 Oscilloscope, and recorded in a computer, with a LabVIEW program, for later post-processing.

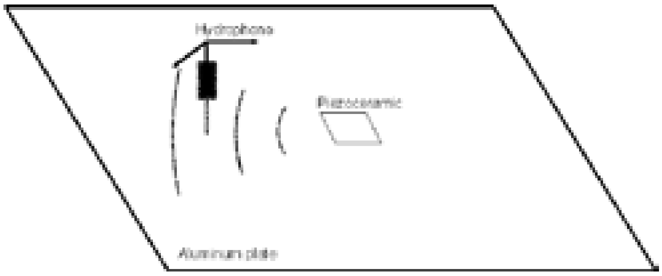

Fig. 1- Ceramic position on the aluminum plate.

Next another piezoceramic was bonded on the other side of the plate in front of the first. By exciting the second actuator in phase with the first one, the symmetric mode, S0, is reinforced whereas the antisymmetric mode, A0, is partially cancelled. When exciting the two actuators out of phase, the A0 mode is then enhanced respect to the S0. A MATLAB program was developed to obtain and plot the experimental dispersion curves by applying a 2D FFT algorithm (5) to the data collected.

The analytical dispersion curves were also calculated in MATLAB to compare the agreement with the experimental ones..

3. RESULTS AND DISCUSSION

Figure 2 shows the analytical dispersion curves, of an aluminum plate of thickness 2h, obtained by solving the Rayleigh-Lamb frequency equations. At a given excitation frequency, solutions of the characteristic equation yields the eigenvalues for the wavenumbers.

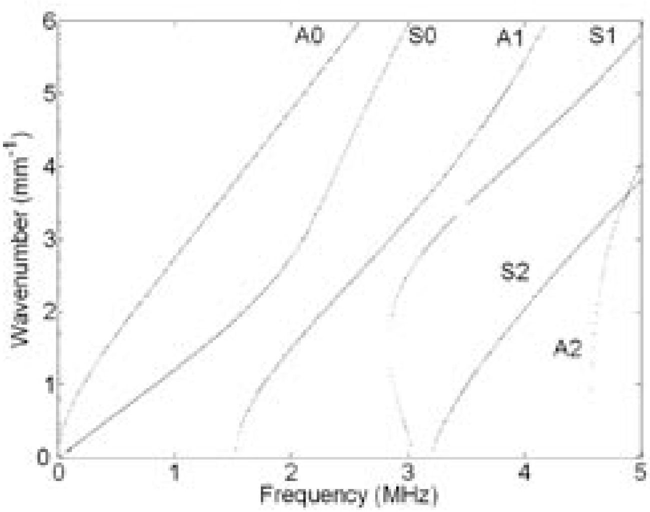

Fig. 2- Analytical dispersion curves for an aluminum plate of thickness 2h obtained solving the Rayleigh-Lamb equations.

The Rayleigh-Lamb frequency equations can be written as

$$\frac{\tan(qh)}{\tan(ph)} = -\left[\frac{4k^2pq}{\left(q^2-k^2\right)^2}\right]^{\pm 1} \qquad [1]$$

where +1 applies for symmetric modes, while -1 applies for antisymmetric modes. The variables p and q are defined as:

$$p^2 = \left(\frac{\omega^2}{c_L}\right) - k^2 \text{ and } q^2 = \left(\frac{\omega^2}{c_T}\right) - k^2 \qquad [2]$$

The wavenumber k is numerically equal to ω/c_p, where c_p is the phase velocity of the Lamb wave mode and ω is the circular frequency. The phase velocity is related to the wavelength by the simple relation

$$c_p = (\omega/2\pi)\ \lambda \qquad [3]$$

When plotting the dispersion curves, we are only interesting in the real solutions of the equations, which present the (undamped) propagating modes of the structure. Rose (6) made a small variation to the Raleigh-Lamb frequency equations shown before. By collecting the terms α and β, the equations take on only real values for real or pure imaginary wavenumbers k. The equations become:

$$\frac{\tan(qh)}{q} + \frac{4k^2 p \tan(ph)}{\left(q^2-k^2\right)^2} = 0 \qquad [4]$$

for symmetric modes

$$q\tan(qh) + \frac{\left(q^2-k^2\right)^2 \tan(ph)}{4k^2 p} = 0 \qquad [5]$$

for antisymmetric modes

Figure 3 shows a plot of the wavenumber versus the frequency for the symmetric and antisymmetric Lamb waves. Note that, at a given frequency value, several Lamb modes may be present. The branches corresponding to each Lamb mode are clearly identifiable.

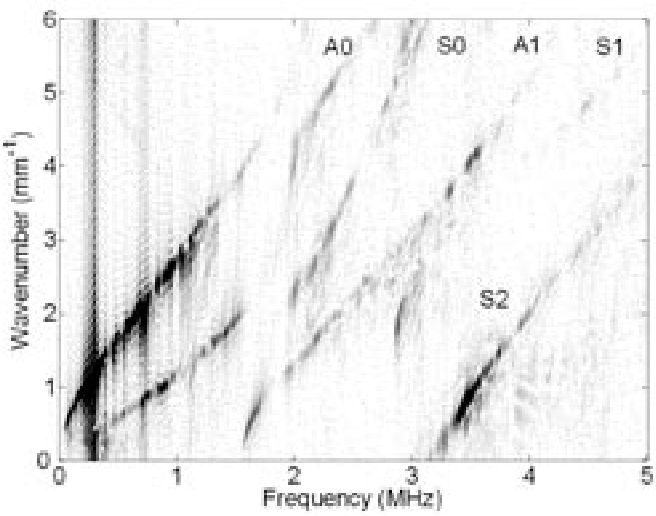

Fig. 3- Experimental dispersion curves for an aluminum plate of thickness 2h calculated applying the 2D FFT algorithm to the data measured with the needle hydrophone.

It is well known that Lamb wave modes are sensitive to different types of damage (7,8,9). Whereas the S0 mode is characterized by its dominant stress and displacement components in the direction of propagation, the A0 mode has significant shear stress and lateral displacement components.

This makes the S0 mode more sensitive to cracks identification while the A0 mode gives useful information when detecting masses.

It can be seen the analytical dispersion curves displayed (figure 2) agree very well with the experimental dispersion curves (figure 3) obtained applying the 2D FFT algorithm to the data collected.

In figure 4, a detailed part of the experimental dispersion curves obtained is shown. The X-axis range is set to be 0 to 500 kHz just to display the changes in the frequency region of interest. Only two modes are present, the antisymmetric fundamental Lamb mode, corresponding to the superior branch and the symmetrical fundamental Lamb mode, inferior branch.

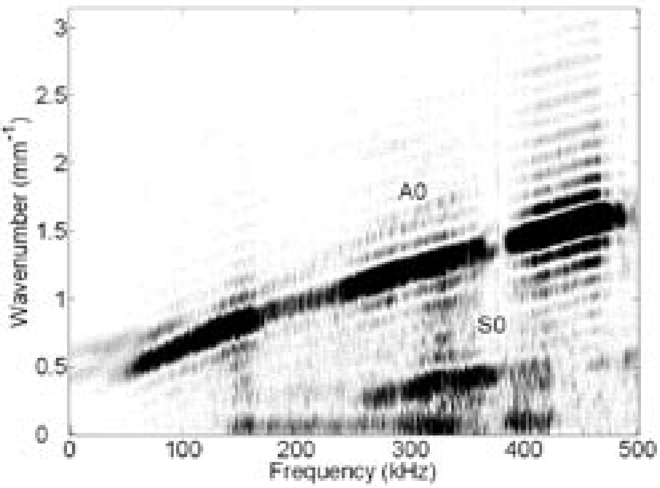

Fig. 4- Detailed part of the symmetric and antisymmetric modes showing the frequency region of interest of the experimental dispersion curves.

When exciting the two actuators in phase (figure 5), it can be seen that the antisymmetric mode, A0, is almost cancelled whereas the symmetric mode, S0, is still present. The superior branch (A0) practically extinguish while the inferior one (S0) remains present.

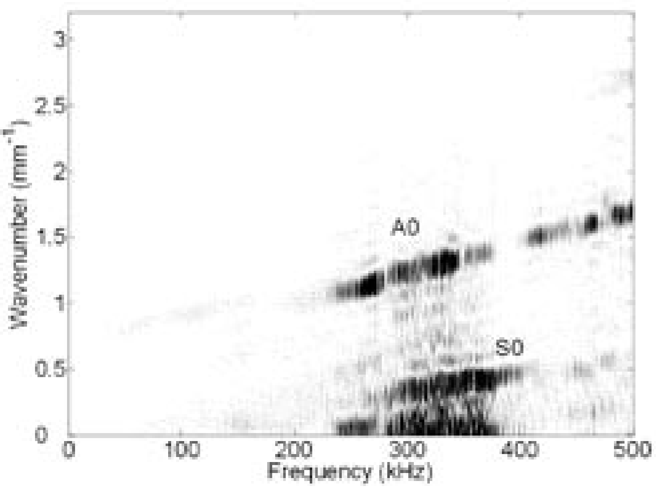

Fig. 5- Reinforcement of the symmetric Lamb mode and cancellation of the antisymmetric one by exciting the two actuators in phase.

In the case of figure 6, when exciting the two actuators out of phase, is the antisymmetric mode which remains unaltered whereas the symmetric mode is cancelled. This can be noticed in the figure by observing the antisymmetric branch is still present and the other branch corresponding to the symmetric mode disappears.

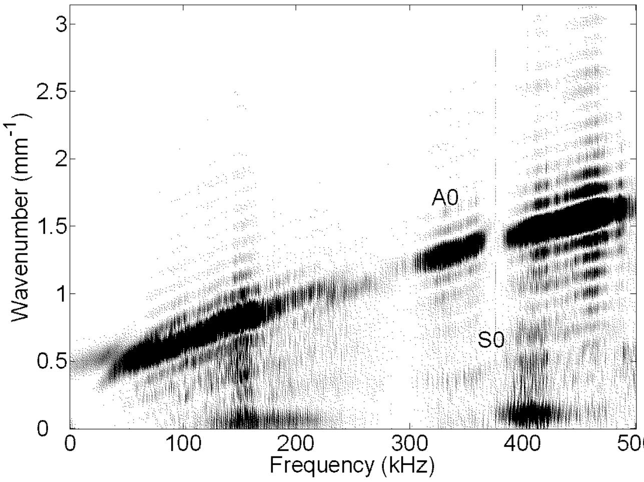

Fig. 6- Reinforcement of the antisymmetric Lamb mode and cancellation of the symmetric one by exciting the two actuators out of phase.

4. CONCLUSIONS

The experimental dispersion curves of an aluminum plate obtained with the 2D FFT algorithm show a very good agreement with the analytical dispersion curves calculated.

Bonding another piezoceramic in the appropriate location of the plate has demonstrated to be an easy and effective method to selectively filter individual Lamb modes.

By filtering the appropriated Lamb modes, defects identification can be achieved easily. In this way cracks identification would be done using the symmetric mode whereas the antisymmetric mode would be useful on bonded masses identification.

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