UTILITY OF LAMB WAVES FOR NEAR SURFACE CRACK DETECTION

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INTRODUCTION

Ultrasonic waves have a long history in detection of surface breaking cracks. Attempts are being made to use guided waves as a defect detection tool in aging skin structures in aircrafts and in the power generation industries as these waves offer a great advantage over conventional bulks waves. Guided waves can be excited at one position and allowed to propagate considerable distances before attenuating. Depending on the configuration employed for defect detection, reflected or received waveforms give information regarding the integrity of the structure along the line of sight. This description makes the technique look rather simple. Particularly, NDT utilizing Lamb waves is more complex due to the existence of two or more modes at any given frequency. Success was reported by several authors on defect detection using Lamb waves. Brief or no explanation was given on the reasons behind the choice of specific excitation frequencies and incident angles. The emphasis was solely on the defect detection aspects.

Presented in this paper is an extension of an intuitively based mode selection criterion proposed by Ditri et.al [1], namely the mode's energy distribution across the thickness of the layer. Albeit based on the same criteria, it was proposed in this work that examining the variation of the available energy at the surface along each mode will be sufficient to choose an optimum mode. The theoretical predictions of sensitivity by wave structure study are compared against a recently developed hybrid Boundary Element Method (BEM) [2]. The sensitivity is experimentally verified using optimum points chosen using this criteria.

BACKGROUND

Presence of two or more modes at any given frequency and every point on each mode possessing its own unique vibrational characteristics calls for a robust mode

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selection criteria. Upon calculating the proper frequency and wave number value using the *Rayleigh Lamb* frequency equations, the vibrational parameters can be calculated using standard formulas [3]. In [1] the authors approach was to study the variation of the energy all along the thickness of the layer. A new format for customary dispersion curves or frequency, f vs phase velocity is introduced in [4], which enables one to have a global perspective regarding the variation of the key parameters along each mode on the surface of the layer. Same notations as in [1] are used and the energy criterion is re-introduced. The rate of energy transport by a given mode per unit cross-sectional area of the layer can be written in terms of stresses and velocity fields as,

$$\langle P_z \rangle = -\frac{1}{2}\left\{\tilde{v}_y \tau_{yz} + \tilde{v}_z \sigma_{zz}\right\} \qquad (1)$$

Integrating (1) across the thickness of the layer yields the time averaged power flow in the z direction per unit width in the x direction, denoted by $<P_{nn}>$. The percent of the total energy flow rate $\%P_{nn}$(surface) available at the surface can be calculated by taking the ratio of $<P_{surface}>$ and $<P_{nn}>$. This parameter is used as the third axis of Figure 1 in the global dispersion curves thus increasing their utility. Hence the name utility dispersion curves. Shown in Figure 1 are the utility dispersion curves where the z axis is the amount of energy (labeled as normalized power) available at the surface. Examining these 3D plots one can read the % energy (power) available at the surface for a given fd and phase velocity value. The symmetric and anti-symmetric families are presented as two different plots to enable the reader to follow the curves with ease.

By impinging a guided wave mode with maximum energy concentration on the surface, an improved signal to noise ratio will be observed for near surface defect detection. The variations of the amount of the total power available at the surface for A_1 mode is shown in Figure 2. For the two points chosen along A_1, there is a 68% difference in the total power available at the surface as shown in Figure 2.

BOUNDARY ELEMENT METHOD

A hybrid Boundary Element Method (BEM) developed recently on the basis of the combination of the elastodynamic boundary integral equation and Lamb wave normal mode expansion technique has been applied to the study of guided wave interactions with arbitrary scatters [2]. In this work, BEM is applied to study two specific points to establish reflection and transmission coefficients as a function of crack depths and there by verify the criteria for mode selection. S_0 mode at 1.0 MHz.mm and A_1 mode at 2.5 MHz.mm are chosen for this study. Comparing these two points in the utility dispersion curves, it may be noted that A_1 at 2.5 MHz.mm has 50% more energy concentration at the surface than the S_0 mode at 1.0 MHz.mm. Presented in Figure 3 are the reflection and transmission coefficients plotted as function of reflector depth give strength to this argument. These theoretical results are then validated aganist experimental results.

Experiments

Fixed angle plexiglas wedges are employed to generate the S_0 and A_1 modes at 1.0 and 2.5 MHZ.mm respectively. A tone burst function generator used here assures a narrow band input to the transducer. The specimen used is an aluminum plate with planar cracks of

5, 10, 15, 20 and 25 percents of through thickness. Time domain measurements are performed using a differential distance method and the theoretical and experimental group velocities are compared to establish the purity of the modes. A reference amplitude for the chosen modes is collected through transmission where the line sight is defect free. Data was collected for each crack depth in pulse echo configuration using two transducers. Sender and receiver are placed adjacent to each other. The data is normalized with the reference amplitude and presented in Figure 4. along with the BEM results. A close agreement is seen as predicted by the energy criteria.

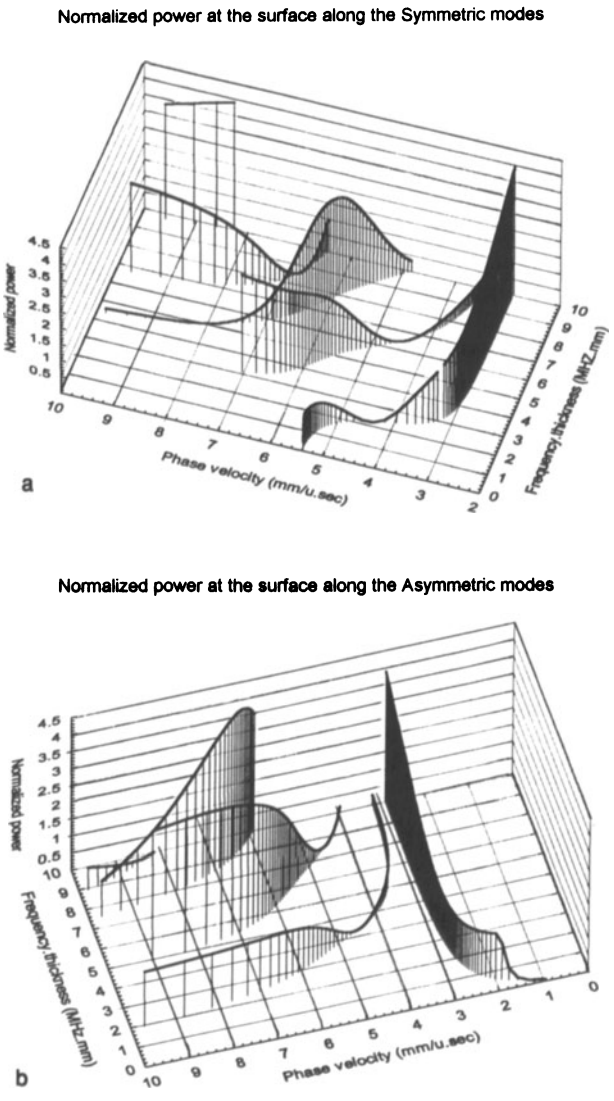

Figure 1. 3-dimentional utility dispersion curves for aluminum showing the % variation of energy available at the surface a) Symmetric family and b) Asymmetric family.

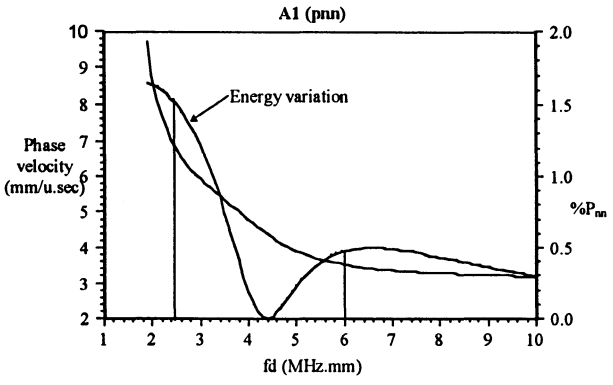

Figure.2. Variation of the in-plane power along the A_1 mode showing point of interest for surface crack and pitting corrosion detection potential.

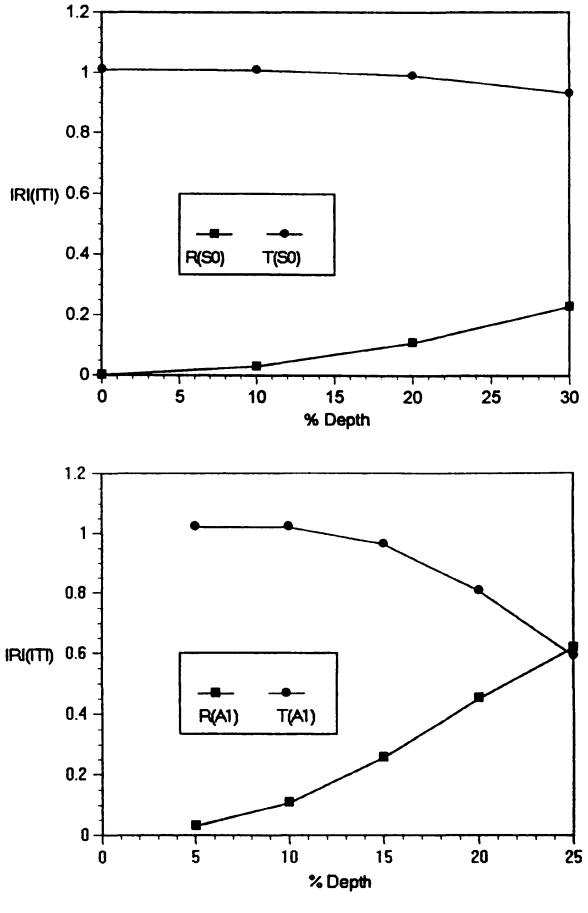

Figure 3. Reflection and transmission coefficients calculated using BEM as function of reflector depth.

CONCLUDING REMARK

Utility dispersion curves were introduced as a mode selection tool for detection of near surface cracks. The concept of using the % energy available at the surface as a mode selection criteria was tested using a recently developed Boundary Element Method and validated experimentally. A close agreement was seen between the theoretical and experimental results. Based on the two points tested the criteria is proved to be sufficient. More experimental work is to be performed to give credence to the criteria.

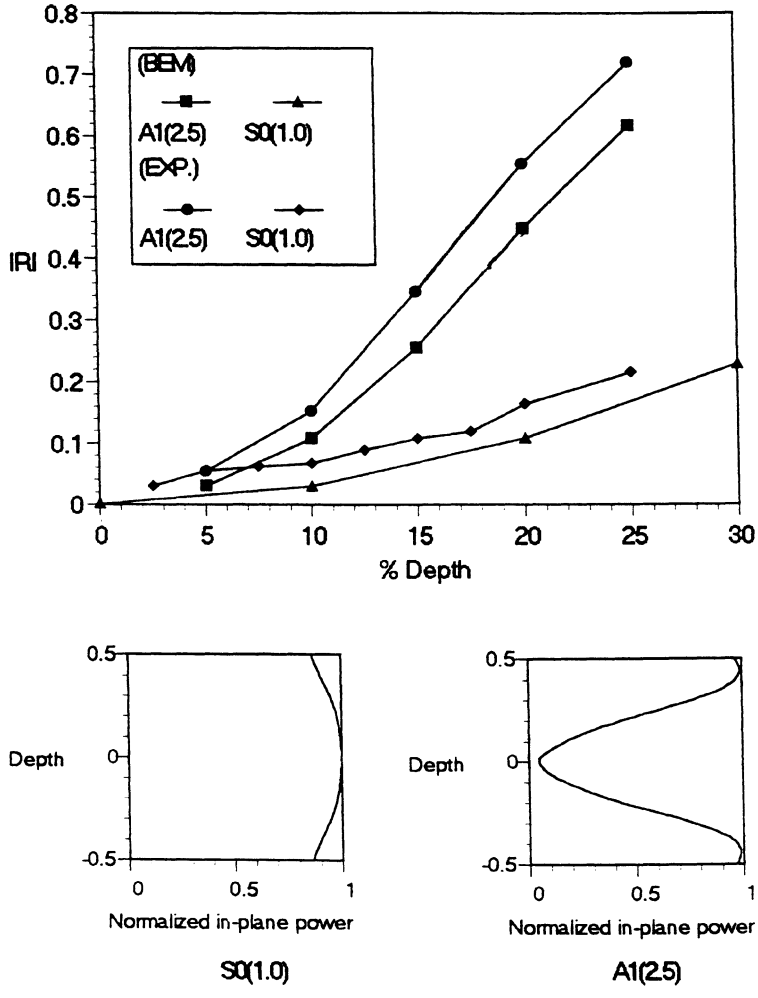

Figure 4. A comparison of theoretical and experimental reflection coefficient plotted as a function of percent through wall reflector depth. The normalized energy distribution curves for S_0 and A_1 modes at the points studied are shown.

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