Simulation of Lamb Wave Propagation with Elastodynamic Finite Integration Technique (EFIT)

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Abstract

This paper presents the numerical modeling of the Lamb wave propagation in plate like structures with the Elastodynamic Finite Integration Technique (EFIT) and its validation with the measured results. In general, Lamb waves offer an attractive method to detect the defects inside long plate like structures efficiently. However, such a non-destructive testing (NDT) requires profound understanding of the Lamb wave propagation in the plates, generation of the symmetric and anti-symmetric modes of different orders and their interaction with the defects of the materials. Modern simulation tools based on numerical methods can be used to model this complex NDT situation. EFIT is an effective tool to model such problems in an efficient way. With the help of the simulation results obtained from the EFIT tool the propagation of different symmetric and anti-symmetric Lamb wave modes is analyzed and thus a proper technique is developed to excite different modes and to separate them from each other precisely. A validation of the numerical results with the measured results is also presented.

Introduction

Lamb waves travel in plate like structures over large distances and are suitable for integrity tests and health monitoring of large scale structures. However, the non-destructive testing (NDT) using Lamb waves suffers from major drawbacks because of the dispersive nature of the wave propagation and the increasing number of propagating modes at higher frequencies [1]. To overcome such difficulties the phased array transducers can be used where a selective excitation of individual modes with a single mechanical setup is possible [2]. A numerical simulation need to be performed to visualize the wave propagation inside the transducer and the excited plate for the ease of analysis of the excitation mechanism.

The Elastodynamic Finite Integration Technique (EFIT) is a well-accepted quantitative modeling tool in non-destructive testing using ultrasound [3]. In this paper, we model the excitation of Lamb wave modes using a phased array transducer and the propagation of guided waves in plate like structures in 2-D using EFIT. Two sets of simulation results are presented. Firstly, the sound propagation in the wedge of a phased array transducer is simulated. The generated Lamb waves in the plate are simulated in the second step. Finally, the simulation results are validated against the measurement results and thus, the feasibility of using EFIT to model the generation and propagation of Lamb waves in plate like structures is studied.

Simulation Results

A phased array transducer is widely used in general ultrasonic testing. Such a transducer facilitates selective excitation of individual modes by defining a trace wavelength λ_{trace} without changing the mechanical set-up (see Fig. 1a). The wedge angle φ_w can be incorporated to the swivel angle α according to

$$\alpha = \sin^{-1}\left(\frac{c_w}{c_{ph}}\right) - \varphi_w \quad , \tag{1}$$

where c_w represents the velocity of the longitudinal wave in wedge and c_{ph} is given by $c_{ph} = f \cdot \lambda_{\text{trace}}$. By controlling the delay time of each element of the phased array transducer electronically we choose the angle of impingement β and thus, a normal force pattern with a trace wavelength λ_{trace} at the surface of the structure [4]. For a thin plate with the thickness d=2 mm and the center frequency of the excitation pulse f=1.5 MHz we compute the following results for the required angles using Eq. 1 and the dispersion curves shown in Fig. 1b:

TABLE 1. Modal behavior for a 2 mm steel plate and a transducers centre frequency of 1.5 MHz.

Mode	λ_{trace} (in mm)	c_{ph} (in m/s)	c_{gr} (in m/s)	β (in °)
A_0	1,9	2865	3160	72
S_0	2,3	3423	2123	53

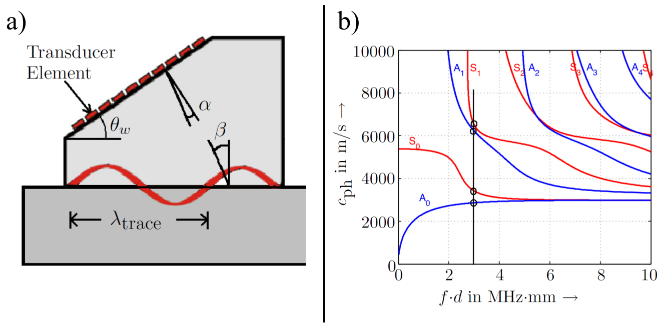

Figure 1: a) Experimental setup using a phased array transducer and b) dispersion diagram for a steel plate with thickness d=2 mm.

According to Table 1, we can excite S_0 mode at β=53°. This analytical value is used to validate the simulation results. The sound field in the wedge is simulated using the EFIT-tool. The simulation results, shown in Fig. 2, represent the sound field at T=11.36 µs. The wedge is assumed to be located in a homogeneous region filled with the same material as the wedge. This facilitates exact computation of the signal at the wedge base in the time-domain.

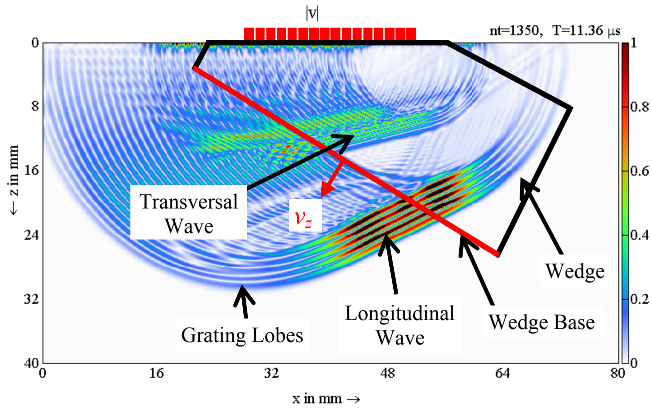

Figure 2: Sound field in wedge using β=53°.

To simplify the problem the reflections inside the wedge are, however, neglected. The small red boxes at the top represent the elements of the phased array transducer, whereas the geometry of the wedge is shown with thick black lines. The normal component of the particle velocity is computed along the base of the wedge and is denoted as v_z in Fig. 2. This component acts as the excitation pulse to generate Lamb waves in the plate in the subsequent simulation. Using this excitation pulse the ultrasonic wave field in a steel plate with a thickness d=2 mm is modeled in Fig. 3 which shows the v_z component in the steel plate at time T=27.35 µs to demonstrate the Lamb waves. Here we observe mostly S_0 mode which agrees with the analytical results presented in Table 1.

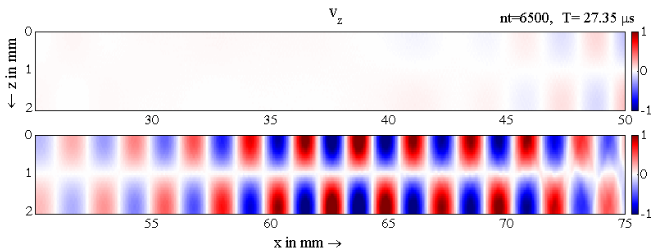

Figure 3: Lamb wave propagation in a plate with thickness d=2 mm (l=25-75 mm is shown here) at a frequency f=1.5 MHz with a phased array transducer using β=53°.

Measurement Results and Validation

The measurements are performed with β = 52° for the S_0 mode. For the experimental analysis of the wave field at the wedge base and on the plate the fields are scanned using a laser vibrometer. A 2-D Fourier transform of the obtained data, in space along the propagation direction and in time domain, yields the measured excitation spectra at the wedge base and in the plate. These spectra are qualitatively compared to the simulated normal component of the particle velocity v_z (k, f). The simulated and the measured spectra at the wedge base are presented in Fig. 4a and Fig. 4b, respectively. The theoretical dispersion curves are over laid with solid and dashed lines. Apart from slight differences in frequency distribution, the agreements between the simulated and the measured wedge base signals are good. The signal, measured in the plate in front of the transducer, is shown in Fig. 4c where mostly those Lamb mode components are excited for which the dispersion curves coincide with the maxima in Fig. 4b. As a result, we observe mostly S_0 mode in the plate which is expected from the theoretical results shown in Table 1 and from the simulation results presented in Fig. 3.

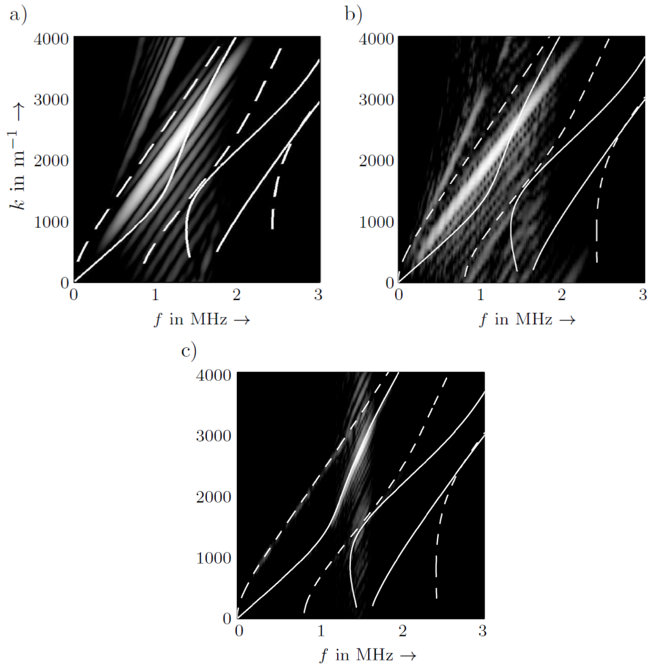

Figure 4: Excitation of S_0 mode for angle of Impingement β = 52°: a) simulated and b) measured spectra at the wedge base; c) excited modes in the plate. Marked: theoretical dispersion curves for symmetric (-) and anti-symmetric (--) modes 0, 1 and 2.

Conclusions

The simulation results, presented in this paper, demonstrate the feasibility of applying EFIT to model the Lamb wave propagation in plate like structures. The corresponding simulation results show good agreement with the theoretical as well as the measured results.

References

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