Lamb wave based nondestructive evaluation on metallic plates

*Zhaoyun Ma, Lingyu Yu

Ph. D. student, Professor, University of South Carolina

Keywords: Lamb wave, NDE, multi-dimensional wavefield analysis, wave scattering

1 Introduction

Lamb wave based Structural health monitoring (SHM) and Nondestructive evaluation (NDE) have been widely studied in plate-like structures since Lamb waves can propagate long distance [1][2], and they are sensitive to a variety of damage[3]-[5]. In this abstract, Lamb wave based damage detection methodology is illustrated on an aluminum plate through a well-developed piezoelectric transducer-scanning laser Doppler vibrometer (PZT-SLDV) system [4]. The damage is simulated with a surface bonded quartz rod on the specimen. 1D and 2D inspection are performed and corresponding time-space wavefields are acquired. Through multidimensional wavefield analysis, the wave-damage interaction is captured, and the damage location is identified for both 1D and 2D inspection.

2 Methodology

Lamb wave wavefields $v(t,\mathbf{x})$ in terms of time (t) and space ($\mathbf{x}$) can be acquired using a PZT-SLDV system. Here, $v(t,\mathbf{x})$ is the surface particle out-of-plane velocity, t is time, and $\mathbf{x}$ is the space vector (x, y). The acquired wavefields can be used to visualize the Lamb wave propagation and interaction with structure discontinuities directly in time and space domain.

In order to characterize Lamb wave modes and observe the wavenumber change in frequency-wavenumber domain, Fourier analysis is performed though fast Fourier transform as,

$$V(f,\mathbf{k}) = F\left[v(t,\mathbf{x})\right] = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} v(t,\mathbf{x}) e^{-i(2\pi ft - k\cdot x)} \mathrm{d}t\mathrm{d}\mathbf{x} \quad (1)$$

Where the t is time and f is the corresponding frequency; $\mathbf{x}$ is the space vector at each scanning point (x, y), and $\mathbf{k}$ is the corresponding wavenumber vector (k_x, k_y); $v(t,\mathbf{x})$ is the measured time-space wavefield in terms of time t and space $\mathbf{x}$. $V(f,\mathbf{k})$ is the resulted frequency-wavenumber (f-k) representation.

3 Experiments and results

A 1-mm aluminum 2024-T3 plate with simulated defect is inspected using a PZT-SLDV NDE system. The experimental setup is shown in Figure 1a. The defect is simulated with a 10-mm diameter quartz rod bonded on the specimen surface as shown in Figure 1b. A 0.2-mm thick PZT with 7 mm diameter is employed as actuator and a SLDV system (Polytec PSV-400-M2) is used for Lamb wave sensing. A 3-count toneburst at 120 kHz is generated through a function generator and amplified to 50 V_{pp} through an amplifier. Through in-plane piezoelectric coupling of the PZT actuator, Lamb waves are excited in the testing plates. SLDV laser head is placed normal to the specimen so that only the out-of-plane particle velocity will be measured.

Cartesian coordinates are employed with excitation point set as origin. The defect is located at y = 50 mm. 1D line scan (y = 10-80 mm) is performed with 1-mm spatial resolution (schematic shown in Figure 2a). The measured time-space wavefield $v(t,x)$ is shown in Figure 2b. One can see that strong incident waves propagate along the scanning line until they encounter the defects (quartz tip at y=45 mm). Some waves transmitted, while some waves reflected after interaction with the defect.

2D area scanning (schematic shown in Figure 2c) is performed in order to observe wave-defect interaction details. The scanning area is 60 mm × 70 mm with 1-mm spatial resolution. The measured time-space wavefield $v(t,\mathbf{x})$ is shown in Figure 2d at selected time 35, 50 and 65 μs. Strong incident waves are observed at 35 μs, and then the waves encounter the defect and scattered at 50 μs. Waves bypass the defect and thus weak waves with little energy transmitted after the defect.

Fourier analysis is performed for wavefields obtained from 1D and 2D inspection. The obtained *f-k* spectrum for 1D inspection is plotted in Figure 3a. Strong incident A_0 with positive wavenumber and weak reflected A_0 with negative wavenumber are observed. For 2D inspection, the wavenumber spectrum under excitation frequency 120 kHz is obtained and plotted in Figure 3b. Strong incident A_0 is observed, while weak scattered A_0 appeared along the theoretical A_0 wavenumber curve.

4 Conclusions

With Lamb wave wavefield analysis, the defect is detected, and the wave-defect interaction is captured for both 1D and 2D inspection. The surface bonded quartz acts as a new scatter source thus wave scattering is observed. Through Fourier analysis, wavenumber variation is obtained in frequency-wavenumber domain, and the observation is consistent with that in time-space wavefield.

5 Reference

[1] Rose, J. L. (1999) *Ultrasonic Waves in Solid Media*. Cambridge: Cambridge University Press, 1999.

[2] Yu, L.; Leckey, C. A. and Tian, Z. (2013). "Study on crack scattering in aluminum plates with Lamb wave frequency-wavenumber analysis," *Smart Materials and Structures*, Vol. 22, No. 6, p. 065019, 2013.

[3] Alleyne, D. N. and Cawley, P. (1992) "The Interaction of Lamb Waves with Defects," *Ieee* Transactions *on Ultrasonics Ferroelectrics and Frequency Control*, Vol. 39, pp. 381-397, 1992.

[4] Yu, L.; Leckey, C. A. and Tian, Z. (2013). "Study on crack scattering in aluminum plates with Lamb wave frequency-wavenumber analysis," *Smart Materials and Structures*, Vol. 22, No. 6, p. 065019, 2013.

[5] Tian, Z.; Yu, L.; Leckey, C. and Seebo, J. (2015) "Guided wave imaging for detection and evaluation of impact-induced delamination in composites," *Smart Materials and Structures*, Vol. 24, No. 10, pp.105019, 2015.

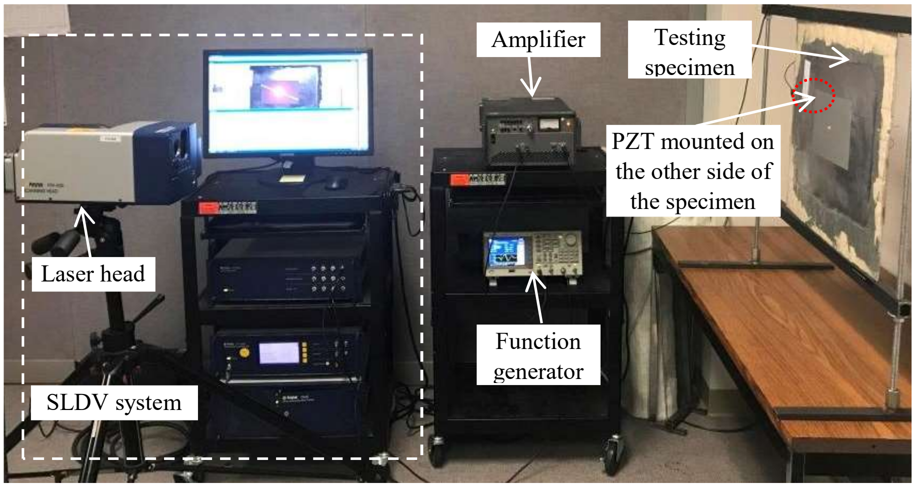

Figure 1 Experimental setup of the PZT-SLDV NDE system

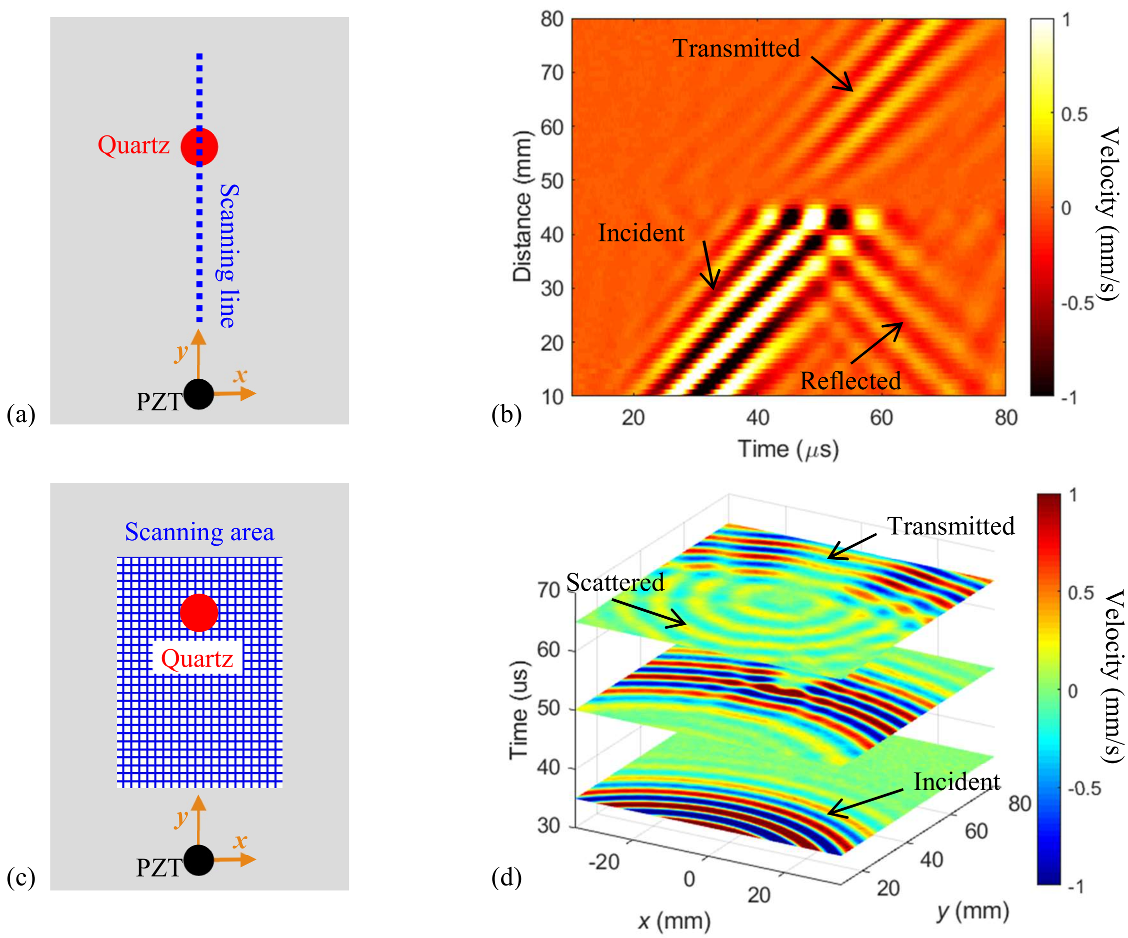

Figure 2 1D inspection: (a) schematic, and (b) time-space wavefield; 2D inspection: (c) schematic, and (b) space wavefield at 35, 50 and 65 μs

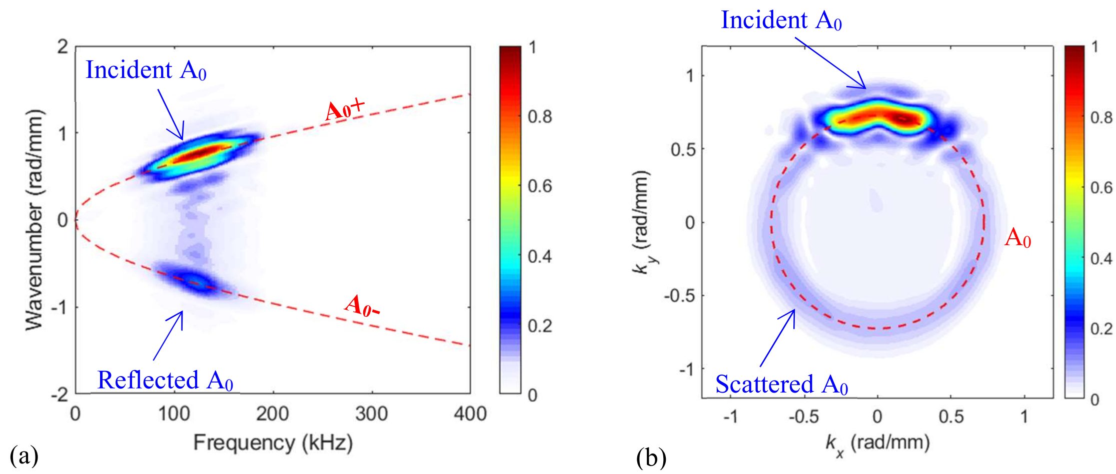

Figure 3 Frequency-wavenumber analysis: (a) *f-k* spectra obtained from 1D inspection, and (b) wavenumber spectrum at 120 kHz obtained from 2D inspection. Note the red dash lines in (a) are theoretical Lamb wave A_0 mode, and the plotted red dash circle in (b) is the theoretical A_0 wavenumber curve at 120 kHz