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Characterization of mechanical and geometrical properties of a tube with axial and circumferential guided waves

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ABSTRACT

Guided waves propagating in cylindrical tubes are frequently applied for the characterization of material or geometrical properties of tubes. In a tube, guided waves can propagate in the axial direction and called axial guided waves, or in the circumferential direction called circumferential guided waves. Dispersion spectra for the axial and circumferential guided waves share some common behaviors and however exhibit some particular behaviors of their own. This study provides an investigation with theoretical modeling, experimental measurements, and a simplex-based inversion procedure to explore the similarity and difference between the axial guided waves and circumferential guided waves, aiming at providing useful information while axial and circumferential guided waves are applied in the area of material characterization. The sensitivity to the radius curvature for the circumferential guided waves dispersion spectra is a major point that makes circumferential guided waves different from axial guided waves. For the purpose of material characterization, both axial and circumferential guided waves are able to extract an elastic moduli and wall-thickness information from the dispersion spectra, however, radius information can only be extracted from the circumferential guided waves spectra.

1. Introduction

Motivated by various practical applications, researches in the nondestructive characterization of material or geometrical properties of tubes continue to be interested. For example, in the oil industry guided waves have been used for the inspection of pipelines involving with defects [1–5], thickness of tubes [6], and coating thickness [7]. In nuclear industry, geometrical and material properties of Zircaloy cladding tubes need to be evaluated for the structure integrity of fuel while the fuel are expected to extend their service life for economic operation [8–12]. In the area of biomedical applications, evaluation of bone properties remains as popular issue in the researches related to osteoporosis [13–16].

Among various techniques available for nondestructive characterization of material properties, those employing ultrasound techniques have been popular, due to the inherited nondestructive and convenient natures. Ultrasound techniques employing bulk wave technique are frequently used for material characterizations. Recently, ultrasound techniques based on guided waves draw more attention from researcher's attention due to (a) long range inspection and (b) suitable for thin-walled tubes. Guided waves propagating in tubes can be grouped into two types, namely, axially propagating guided waves and circumferentially propagating guided waves. The axial guided waves can be further categorized into longitudinal mode, flexural mode and torsional mode [17]. Both axial and circumferential guided waves are potential candidates for the purpose of material characterization of tubular objects. While axial or circumferential guided waves are used in material characterization, their propagation behaviors need to be investigated.

To extract properties from dispersion spectra of guided waves, inversion process based on simplex algorism is a common procedure. In 1965, Nelder and Mead proposed the simplex method for solving minimum solution [18]. Since then, the simplex method was applied to solve regression curve [19], to obtain mechanical properties from leaky Lamb wave measurements on composite materials [20], and to calculate material properties of thin film from measurements with scanning acoustic microscope (SAM) [21].

This study provides an investigation with theoretical calculation, experimental measurements, and a simplex-based inversion procedure to explore the similarity and difference between the axial and circumferential guided waves, aiming at providing useful information while these two categories of guided waves serve as candidates in the area of material characterization.

2. Laser ultrasound measurements

A laser-generation/laser-detection laser ultrasound technique (LUT) is used for the measurements of dispersion spectra of circumferential and axial guided waves. As shown in Fig. 1, the

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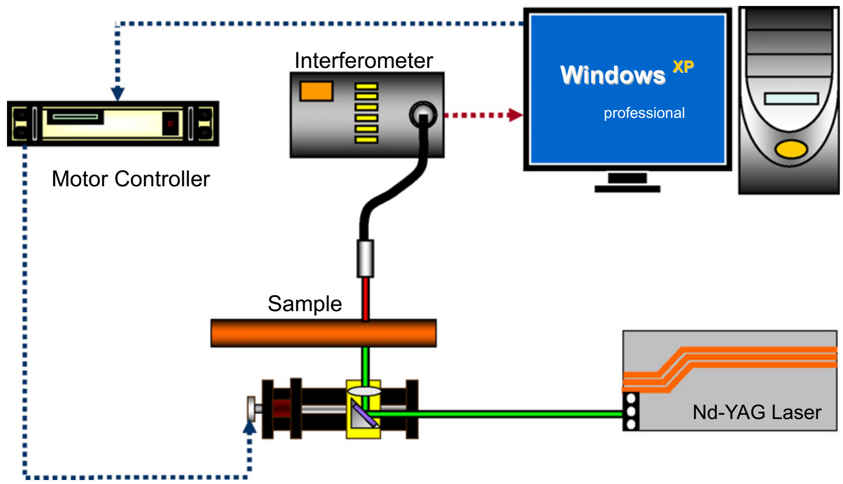

Fig. 1. Experimental configuration of the LUT.

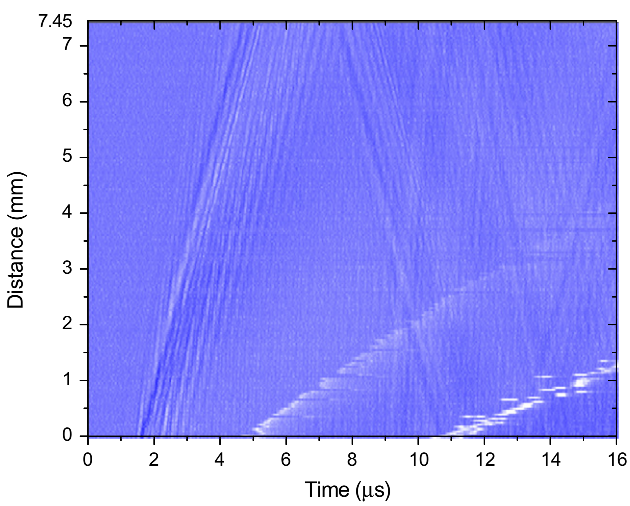

Fig. 2. B-scan data for the circumferential guided wave.

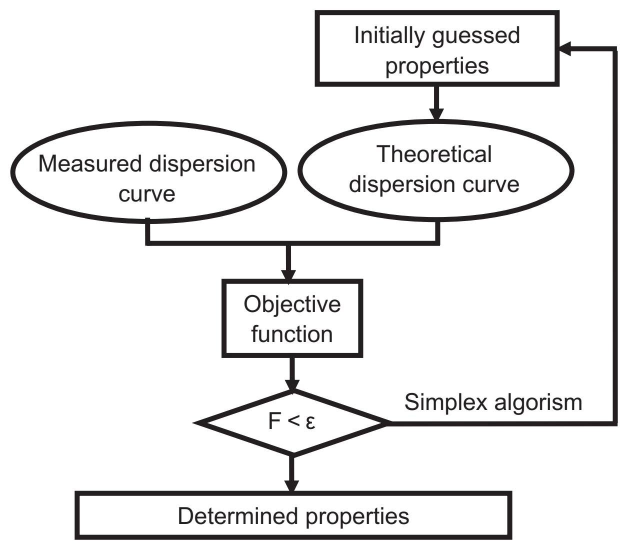

Fig. 3. A flowchart showing the inversion procedure.

experimental configuration consists of a pulsed laser for the generation of guided waves and a laser probe for the detection. The excitation source is a Nd:YAG laser with a power of approximately 100 mJ, a 532 nm wavelength, and a pulse duration of 6.6 ns. A laser Doppler optical receiver (OFV 511 and OFV 2700 by Polytec, Germany) is applied to detect the guided waves. A B-scan scheme is used for the measurement of the dispersion behaviors of guided waves. During the scanning, the optical detector is located at a fixed point, while the generation laser beam is scanned in the axial or circumferential direction. Along each of the paths there are 200 scanning steps with a step size of 0.05 mm. By accumulating the 200 steps, Fig. 2 shows the B-scan data in a gray scale format for the circumferential guided wave.

A two-dimensional fast Fourier transform (2D-FFT), first taken with respect to time and second with respect to scanned position, is used to obtain the dispersion spectra in the temporal frequency versus spatial frequency ($\omega - k$) domain, where a ridge finding involving with peak-detection algorism is used to identify the guided modes.

3. Inversion with simplex algorism

Following the measurements on the dispersion spectra of guided modes propagating in a tube, an inversion procedure can

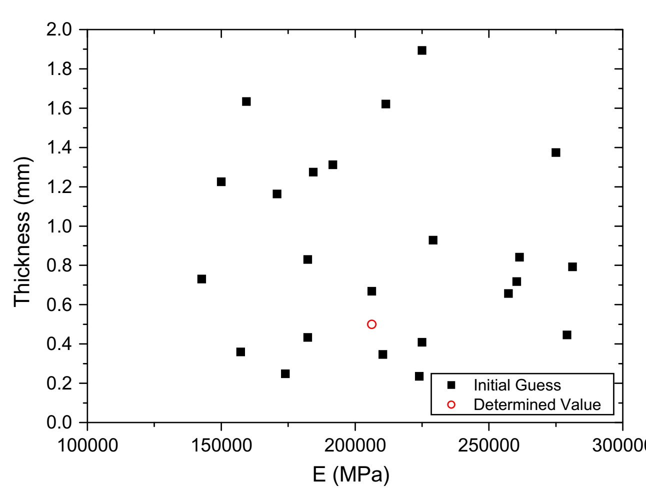

Fig. 4. Initially guessed and determined properties in the benchmark test.