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Guided Wave Based Characterization of Mechanical Parameters and Wall Thickness of Metal Tubes

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Summary:

Modelling phenomena of structural mechanics requires the knowledge of mechanical parameters of the utilized material. Moulding of the material during the manufacturing process, e.g. drawing pipes, may alter the material properties slightly. In comparison to classical destructive measurement methods, which involve samples of specific shapes, or classical ultrasonic testing, requiring a minimum material thickness, the proposed method based on laser vibrometry and guided ultrasonic enables a simultaneous estimation of the elastic constants and the wall thickness of a pipe.

Keywords: guided waves, ultrasound, material characterization, inverse method, numerical modelling

Introduction

The development of new measurement devices often involves detailed simulations in advance. In order to make more precise predictions of the later behaviour, appropriate material parameters are necessary. Modelling structural mechanical problems, e.g. eigenmode analysis, depends on the linear elastic constants, density and geometry. Classical ultrasound-based methods of measuring the elastic constants rely on time-of-flight measurements. However, the axial resolution limits the minimum material thickness, which may be investigated [1].

Recently, researchers started to utilize guided ultrasonic waves, as they provide a greater sensitivity. Propagating guided waves split into different modes, each possessing a unique frequency-dependent wave speed represented by dispersion curves. These mode properties depend on the material and geometric constants and are therefore well suited for material characterization purposes.

The research on guided wave based material characterization started with analytical calculations on time-domain data [2] and went on to model-based characterization of isotropic [4] and orthotropic [3] plates as well as plates with nonlinear material behaviour [5]. In a recent work [6], we proposed an advancement of characterization of elastic constants of plates by using long-time broadband signals, a laser-scanning measurement system and an optimized modelling method. In this contribution, we want to transfer these ideas to thinwalled pipes with a view to precisely determine the averaged wall thickness and the pipe's linear elastic constants.

Measurement Setup

The aim of measurements with the setup shown in Fig. 1 is the acquisition of frequency resolved wavenumbers by measuring time-space dependent data of propagating guided waves. The waves are excited by a bonded piezoelectric element of size 35x2.9x0.2 mm^3, driven by an arbitrary function generator and a voltage amplifier. We use coded signals to excite the piezoelectric element [6]. Metallic pipes with diameters around 60 mm and wall thicknesses of 1 mm to 2 mm are mounted on a high precision rotation stage. The pipe is rotated in 630 steps with about 0.01 rad per step. To obtain wavenumbers, we transform the rotation angle to Cartesian coordinates using the nominal outer radius of the pipe. Time-dependent normal surface velocities are measured by a

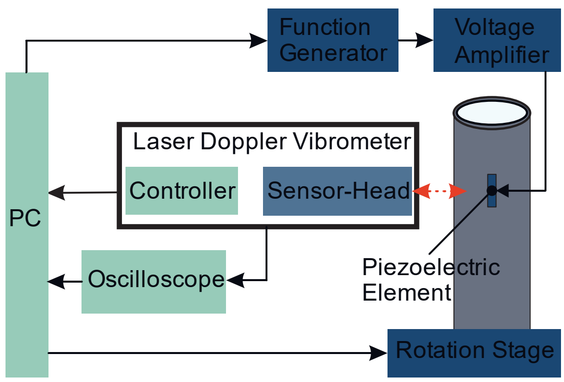

Fig. 1. Measurement setup for the acquisition of time and space dependent normal surface velocities.

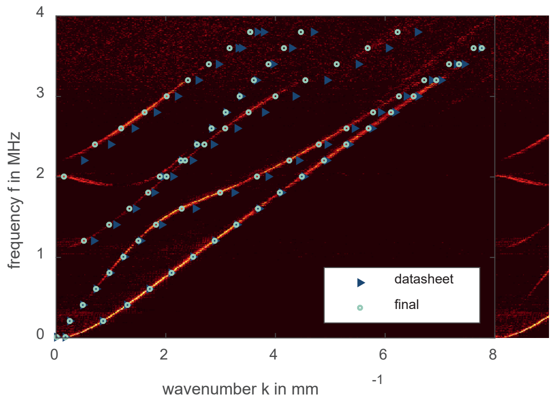

Fig. 2. Comparison of dispersion curves from simulation with start and final parameters plotted over measurement data. Steel 1.4301; D=60.3 mm, h=1.5 mm.

laser Doppler vibrometer and are recorded by an oscilloscope. The vibrometer's nominal bandwidth is 1.5 MHz, but since absolute velocity amplitudes are not relevant for our examination, we were able to capture dispersion curves up to 3 MHz.

Inverse Characterization Algorithm

Frequency-dependent wavenumbers are obtained from measured normal surface velocities by taking the 2D fast Fourier transform (see Fig. 2). A numerical model, shown in [6], is iteratively optimized in such way that the quadratic deviation between the measured wavenumbers and the calculated ones is minimized. The parameter vector ***p***, containing the desired constants, namely the longitudinal and transversal wavespeeds c_l, c_t and the wall thickness h, gets adjusted during each iteration step. The starting values are chosen as the nominal values from literature. For convergence analysis, ***p*** has been randomly altered by ±10%. In most cases, the algorithm converged in a few steps and returned accurate final parameters (Fig. 2).

Results

Samples of two aluminium, one steel and one brass alloy were investigated. Parameters for all samples could be found such that measurement data and model output match (see Fig. 2). During the repetition of the measurement procedure, uncertainties of parameters with a standard deviation of about 1% were observed. The obtained results show a good agreement with reference values from conventional time-of-flight measurements with longitudinal and shear wave contact transducers, as can be seen in Tab. 1.

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Tab. 1: Results of characterization method. Reference measurements are shown in columns REF. Results of inverse characterization and percentage deviation follow in columns IC.

material	REF			IC		
	h (mm)	c_l (m/s)	c_t (m/s)	h (mm) dev (%)	c_l (m/s) dev (%)	c_t (m/s) dev (%)
AlCuMg	1.13	-	3280	1.08 (4.4)	6700 (-)	3090 (5.8)
AlMgSi	1.94	6450	3230	1.95 (0.5)	6480 (0.5)	3200 (1.2)
Steel	-	5980	3190	1.44 (-)	5770 (3.5)	3190 (0.1)
Brass	1.05	4730	2260	1.05 (5.00)	4630 (2.1)	2190 (3.1)

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