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Investigation into the bistatic evolution of the acoustic scattering from a cylindrical shell using time-frequency analysis

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ABSTRACT

The time and frequency analyses of the acoustic scattering by an elastic cylindrical shell in bistatic method show that the arrival times of the echoes and the resonance frequencies of the elastic waves propagating in and around the cylindrical shell are a function of the bistatic angle, β, between the emitter and receiver transducers. The aim of this work is to explain the observed results in time and frequency domains using time-frequency analysis and graphical interpretations. The performance of four widely used time-frequency representations, the Smoothed Pseudo Wigner-Ville (SPWV), the Spectrogram (SP), the reassignment SPWV, and the reassignment SP, are studied. The investigation into the evolution of the time-frequency plane as a function of the bistatic angle β shows that there are the waves propagating in counter-clockwise direction (labeled wave+) and the waves which propagate in clockwise direction (labeled waves−). In this paper the A, S_0, and A_1 circumferential waves are investigated. The graphical interpretations are used to explain the formation mechanism of these waves and the acoustic scattering in monostatic and bistatic configurations. The delay between the echoes of the waves+ and those of the waves− is expressed in the case of the circumnavigating wave (Scholte-Stoneley wave). This study shows that the observed waves at $\beta = 0°$ and $\beta = 180°$ are the result of the constructive interferences between the waves+ and the waves−. A comparative study of the physical properties (group velocity dispersion and cut-off frequency) of the waves+, the waves− and the waves observed in monostatic configuration is conducted. Furthermore, it is shown that the ability of the time-frequency representation to highlight the waves+ and the waves− is very useful, for example, for the detection and the localization of defaults, the classification purposes, etc.

1. Introduction

The scattering of an acoustic wave from both infinite and finite cylindrical components has been investigated theoretically [1–4] and experimentally [5–11] by many authors. Since these components are extensively used in engineering structures. The first study of the scattering of a normal-incident plane acoustic wave upon an immersed infinite cylinder is due to Faran [12]. Flax et al. [2] investigated the scattering from an elastic cylinder of an oblique plane acoustic wave. They proposed the Reso-

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nance Scattering Theory (RST) for drawing the resonance spectra of a cylinder excited by a plane wave. Rumerman [13] used the Sommerfeld-Watson transform to study acoustic the scattering of an oblique incident wave upon cylindrical shells. Li and Ueda [14] developed a theoretical model for the acoustic scattered field based on phase angles associated with partial scattered waves. Veksler [1], Uberall [15] and Gaunaurd [16] have investigated the acoustic scattering of a plane harmonic wave by the cylindrical shell. They considered different angles of the incident wave with the normal to the shell. Maze et al. [17] for the first time developed an experimental Method for the Isolation and Identification of Resonances (MIIR) of the cylinder and cylindrical shell. This method is based on the fact that for each resonance during the forced insonification, the target stores the energy that is reradiated into the surrounding fluid when the excitation stops. Mitri [18] investigated the acoustic backscattering enhancements for incidence angles larger than 40° for different elastic and viscoelastic infinite cylinders. Rajabi et al. [4] shown that the radiation force is a composition of three components: the background component, the resonant component and their interaction. Brill et al. [19] studied the sound scattering from finite cylindrical shell. They considered the geometrical reflexion. Haumesser et al. [20] investigated the first guided wave elastic cylindrical shells of finite lengths. Morse et al. [21,22] used a hybrid method combining full elasticity theory and the Kirchhoff diffraction integral to study the frequency-angle domain above the critical angles of the membrane waves. The analysis of the acoustic scattering of a normal incidence plane wave upon cylindrical shell shows that the circumferential waves are generated in the shell and on the water/shell interface. The propagation of these waves gives rise to the appearance of the standing waves and consequently the resonances of the cylindrical shell [2,17]. The application of the resonance scattering theory [1,2] allows to understand the mechanisms that lead to the resonances. Each resonance is characterized by a number 'n' of wavelengths around the circumference of the cylindrical shell, this number is named mode of vibration. The circumferential waves are divided into the symmetric (S_i, where i = 0, 1, 2 …) and antisymmetric (A_i) waves [23–26]. At normal incidence, the number and the type of the generated circumferential waves S_i and A_i are linked to the frequency range used and the radius ratio b/a of the studied cylindrical shell (b: inner radius, a: outer radius). When the radius ratio b/a is close to 1, the circumferential waves are equivalent to the Lamb waves on a plate [23,25]. Moreover, an extensive investigation of anisotropic cylinders and cylindrical shells can be found in the literature [27–29].

On the other hand, the use of the time-frequency representation to study the acoustic scattering has received particular attention. This representation is used to surmount the limitation of the time and frequency analyses. Indeed, the time analysis is used, for example to distinguish between the non-resonant and resonant parts of the acoustic scattering, identify the arrival time of circumferential wave echoes, etc., but does not allow to have the information about the resonance of the scatter and have sometimes suffered from the overlapping phenomenon. In contrast, the frequency analysis is useful to study the resonances, but cannot display the time evolution of the acoustic scattering. Morse et al. [30] employed time-frequency analysis to identify and characterize individual ray contributions from generalized lamb waves excited on the truncated cylindrical shell. They used this analysis to identify ray contributions from impulse backscattering measurements. Dariouchy et al. [31] used the Wigner-Ville distribution to follow the evolution of the cut-off frequencies of the antisymmetric circumferential waves as a function radius ratio of the cylindrical shell. Dragonette et al. [32] employed time-frequency analysis to decompose the acoustic scattering from air-filled spherical and finite ribbed cylindrical shells into its distinct components. Magand et al. [33] analyzed the energy of the circumferential waves when both the geometry and the mechanical characteristics of the cylindrical shell are varying. Latif et al. [34,35] for the first time applied time-frequency method to estimate the cut-off frequency and dispersion curves of the circumferential waves. Agounad et al. [36,37] used Smoothed Pseudo Wigner-Ville to characterize an elastic cylindrical shell from the predicted form function. They also used time-frequency properties, such as the group delay, to estimate the properties of the surface waves propagate around the bilayer cylindrical shell. Anderson et al. [38,39] applied the Wigner-Ville distribution to study the bistatic variation of the mid-frequency enhancement (MFE) of the fluid-loaded and thin spherical shell. In addition, many researches have been concerned the proposition and amelioration of the time-frequency methods. Comprehensive reviews of intensive bibliographies can be found in Refs. [40–51].

So far, the majority of the time and frequency analyses and all time-frequency analyses of the acoustic scattering by an elastic cylindrical shell have been concerned the data of the monostatic method [3,7,17,31]. In present work, for the first time we propose to study the evolution of the acoustic scattering in bistatic method. The analysis of the acoustic scattering results in time domain for different values of the bistatic angle, β, between the emitter and receiver transducers shows that the evolution of the acoustic scattering is as a function of this angle. The same phenomenon is observed in the scattering spectrum which is obtained in the forced excitation regime, then in the resonance spectrum that computed in free re-emission regime, and also in the plane of modal identification. Our basic aim is to investigate of this issue using time-frequency analysis. For this purpose, four commonly known time-frequency representations, the spectrogram (SP), the Smoothed pseudo Wigner-Ville (SPWV), the reassignment SP and the reassignment SPWV, were employed. The radius ratio (b/a) of the considered elastic cylindrical shell is fixed at 0.95 and the outer radius is $a = 10$ mm. The investigated reduced frequency ($k_1 a$) interval extends over $0.1 \leq k_1 a \leq 200$, (k_1 is the wave number in the external medium). The circumferential waves A (Scholte-Stoneley wave), S_0 and A_1 are taken into account.

This paper is structured as follows. In section 2, we discuss the acoustic scattering in bistatic method. Section 3 describes the time and frequency analyses of the acoustic scattering in bistatic method. Section 4 presents the bistatic evolution of the acoustic scattering using time-frequency representations. Graphical interpretation of the formation mechanism of the elastic waves is presented in section 5. The estimation of the cut-off frequencies and the dispersion curves of the circumferential waves are summarized in section 6. Finally, section 7 is dedicated to draw conclusions.