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► **To cite this version:**

Said Agounad, Dominique Décultot, Farid Chati, Fernand Leon, Younes Khandouch, et al.. Acoustic scattering from cylindrical shell: monostatic versus bistatic configurations. Forum Acusticum, Dec 2020, Lyon, France. pp.1863-1866, 10.48465/fa.2020.0610 . hal-03240287

HAL Id: hal-03240287

<https://hal.science/hal-03240287>

Submitted on 12 Jun 2021

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ACOUSTIC SCATTERING FROM CYLINDRICAL SHELL: MONOSTATIC VERSUS BISTATIC CONFIGURATIONS

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ABSTRACT

Acoustic scattering is one of the most useful tools for characterization and non-destructive control of cylindrical structures. The record of the scattering field in different angles around the cylindrical shell gives rise for monostatic and bistatic data. This paper presents the comparison between the results obtained in monostatic configuration and those obtained in bistatic configuration. Temporal and spectral analyses show that the chronological and frequency contents of the considered signals are a function of the angle between the emitter and receiver transducers. The angular diagram and smoothed pseudo Wigner-Ville time-frequency representation are used to explain such variation.

1. INTRODUCTION

Cylindrical structures are widely used in several fields such as practical engineering, storage and production of renewable energy transport of fluid and gases...The environmental conditions where these structures are used impose the need for their continuing control. The acoustic scattering is one of the widely used techniques for control of these structures. Many studies for the acoustic scattering from cylindrical structures are available in the literature [1–3]. Maze et al. [4] developed an experimental Method for Identification and Isolation of Resonance (MIIR) of a cylinder and tube. Mitri [5] analyzed the acoustic backscattering enhancements from cylinders for incidence angles larger than 40°. Agounad et al. [6] proposed an analytical model based on normal mode expansion theory and potential functions for studying the acoustic scattering from bilaminated cylindrical shells. They have conducted a comparative study between the results of the acoustic scattering from bilaminated and one-layered cylindrical shells. Agounad et al. [7] investigated the existence condition of zero group velocity waves in the case of bilaminated and one-layered cylindrical shells. Chati et al. [8] studied the acoustic scattering of a normal incident wave from an aluminium tube with a concentric Lu-

cite cylinder coupled with a thin water layer. Rajabi et al. [9] used resonance scattering theory to investigate the steady-state ultrasound radiation characteristics of an infinite cylindrical shell subject to an arbitrary time-harmonic.

The record of the scattering field from the excited cylindrical structure can be done either in monostatic or in bistatic configurations. In the first case, one transducer plays a role of the emitter and receiver. In the second case, the emitter is far from the receiver by a given angle. To the best of our knowledge, few works have been done on the investigation of the acoustic scattering in bistatic configuration. Agounad et al. [10] investigated theoretically the scattering of an acoustic plane wave from an aluminum cylindrical shell. In this reference the authors used clockwise waves (waves- as adopted in this reference) and counterclockwise waves (waves+) to analyse the bistatic evolution of the scattering field. They have conducted a comparative study of the group velocities and cutoff frequencies estimated in monostatic and bistatic configurations. Rajabi [11] employed the resonance scattering theory to determine the background and resonance scattering fields from cylindrical shell. He isolated and classified the stimulated frequencies based on clockwise or counterclockwise propagating around the shell. Anderson et al. [12] employed time-frequency representation to study theoretically and numerically the bistatic variations of the acoustic scattering from air-filled spherical shell. They have studied the time-frequency shifts of the mid frequency enhancement. In addition, an optimal array beamformer based on joint time-frequency shifts is used to enhance the detection of the bistatic scattering signal from spherical shell.

This paper proposes to study experimentally the acoustic scattering in monostatic and bistatic configurations. The use of the angular diagram allows us to explain the difference in frequency content between monostatic and bistatic signals. The waves propagating in clockwise direction (clockwise waves) and those propagating in counterclockwise direction were introduced to assign the patterns observed in time-frequency images.

2. MATERIAL AND METHOD

2.1 Experimental setup

The studied cylindrical shell in the experimental study is made from stainless steel. This material is of density $\rho = 7900 \text{ kg m}^{-3}$, longitudinal velocity $C_L = 5790 \text{ m s}^{-1}$ and transverse velocity $C_T = 3200 \text{ m s}^{-1}$. The radii ratio of the considered cylindrical shell is $b/a = 0.97$, the outer radius is $a = 15.3 \text{ mm}$ and its length is $L = 200 \text{ mm}$. The cavity of the shell is filled with air of longitudinal velocity $C_2 = 340 \text{ m s}^{-1}$ and density $\rho_2 = 1.2 \text{ kg m}^{-3}$. The experiment is led in a rectangular tank (2 m long, 1.5 m wide and 1 m deep) which is filled with water of longitudinal velocity $C_1 = 1470 \text{ m s}^{-1}$ and density $\rho_1 = 1000 \text{ kg m}^{-3}$. The top and bottom extremities of the shell are ended by two thin rubber diaphragms. The broadband Panametrics transducers are used, model V397S-SU, with a central frequency 2.25 MHz. In this experiment two transducers are used, an immobile emitter transducer and a mobile receiver transducer moving around the considered shell in an azimuthal plane. At each azimuthal angle, The receiver transducer measures the temporal response of the excited object.

2.2 Time-frequency method

Many time-frequency methods have been developed to study a given signal jointly in time and frequency. Smoothed Pseudo Wigner-Ville distribution (SPWV) is one of the most used time-frequency methods. This method is a variant of Wigner-Ville distribution [13]. Indeed, the time frequency image obtained by this later includes, in addition of the signal components, the cross interferences between these components. In order to reduce the effect of those interferences, two smoothing functions are introduced in the expression of the Wigner-Ville distribution. The modified expression of the Wigner-Ville distribution is known as SPWV and is given as: [14, 15]:

$$SPWV(t, \omega) = \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} h(\tau)g(t - \eta)x(\eta + \tau/2)x^*(\eta - \tau/2)e^{-i\tau\omega} d\tau d\eta. \quad (1)$$

Where h is a temporal smoothing window and g is a frequency smoothing window. Several functions such as hamming, Gabor and Blackman, can be chosen to simulate the h and g windows.

3. RESULTS AND DISCUSSION

Figures 1.(a) and (b) show two experimental signals of the studied cylindrical shell. The first signal (Fig. 1.(a)) is obtained in monostatic configuration, the second one (Fig. 1.(b)) is obtained in bistatic configuration. These figures show the specular echo, S_0 and A_0 waves. In bistatic configuration, the S_0 wave has two components, the clockwise (CW) and counterclockwise (CCW). Indeed, the excitation of an elastic cylindrical shell by an incident wave gives rise to two kinds of waves, the waves propagating in a clockwise direction and the waves propagating in a

counterclockwise direction. The observed S_0 echoes in monostatic configuration (the emitter coincides with the receiver) are the constructive interference of these components, since in monostatic, CW and CCW waves propagate the same distance. Hence, these waves arrived to the receiver level with a null path difference and the phase difference is multiple of 2π . The first echo of S_0 wave propagating in CW is overlapped with the specular echo (Fig. 1.(b)).

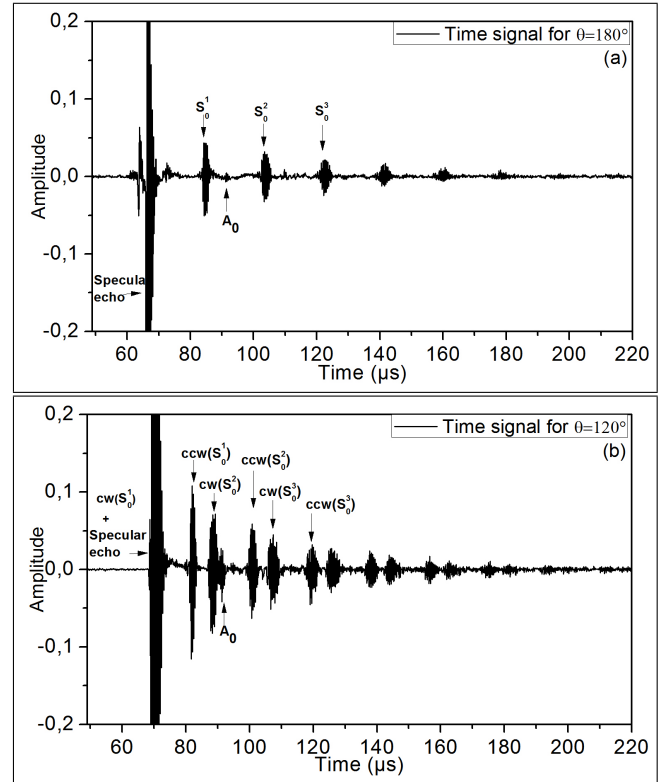


Figure 1. Temporal signals, (a) is obtained in monostatic configuration ($\theta = 180^\circ$) and (b) is obtained in bistatic configuration ($\theta = 120^\circ$), θ is the azimuthal angle.

The resonance spectra of the experimental signals are obtained by inverse Fourier transform of the temporal signal free-specular echo. Figures 2.(a) and (b) show the resonance spectra obtained for $\theta = 180^\circ$ and $\theta = 120^\circ$. These figures depict that there is a difference in frequency content between monostatic (Fig. 2.(a)) and bistatic configuration (Fig. 2.(b)). In bistatic configuration, there is the absence of some resonant frequencies in comparison with the monostatic configuration. This can be explained by the fact that the receiver transducer is in front of a node of the missing frequencies. Indeed, each resonant frequency is corresponding to an integer of nodes and antinodes around the shell, therefore, to detect a given resonant frequency it is necessary that the receiver transducer is in the front of an antinode of that frequency. This can be clearly explained based on Fig. 3 which shows an angular diagram of resonant frequency ($f = 384.7 \text{ KHz}$). This diagram shows that to detect this frequency, the receiver should be par example in position A and B. In contrast, this frequency can not be detected in position C and D.

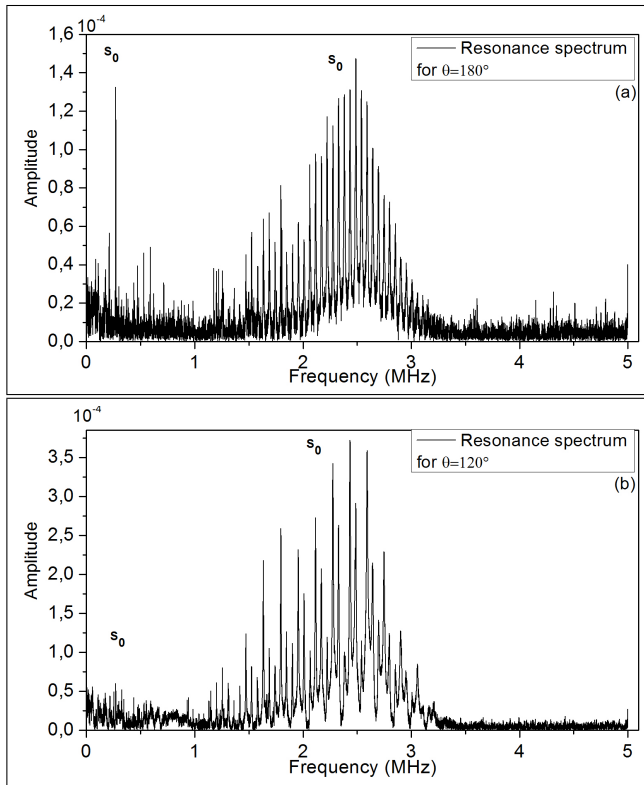


Figure 2. Resonance spectra, (a) is obtained in monostatic configuration ($\theta = 180^\circ$) and (b) is obtained in bistatic configuration ($\theta = 120^\circ$).

The application of time-frequency representation on the experimental signals (figure 1) allows to visualize the evolution of frequency content as a function of time. Figures 4.(a) and (b) show the SPWV images obtained in monostatic and bistatic configurations, respectively. In contrast of temporal presentation, SPWV image shows clearly the clockwise and counterclockwise waves. In addition, this presentation allows to identify with good precision the arrival time of the A_0 wave which is very difficult from temporal presentation (Fig. 1.(b)) due to the overlapping of this wave with $CW(S_0^2)$.

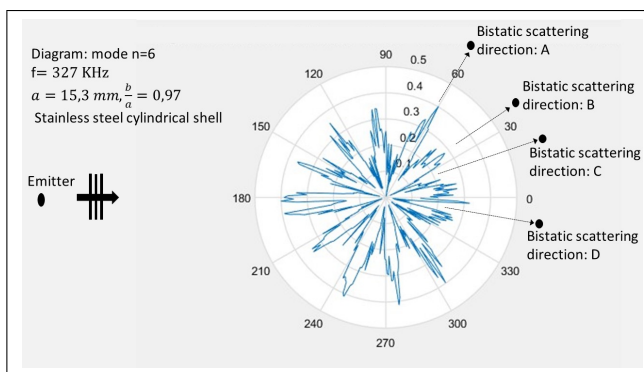


Figure 3. Angular diagram for $f = 327\text{KHz}$ and vibration mode $n=6$

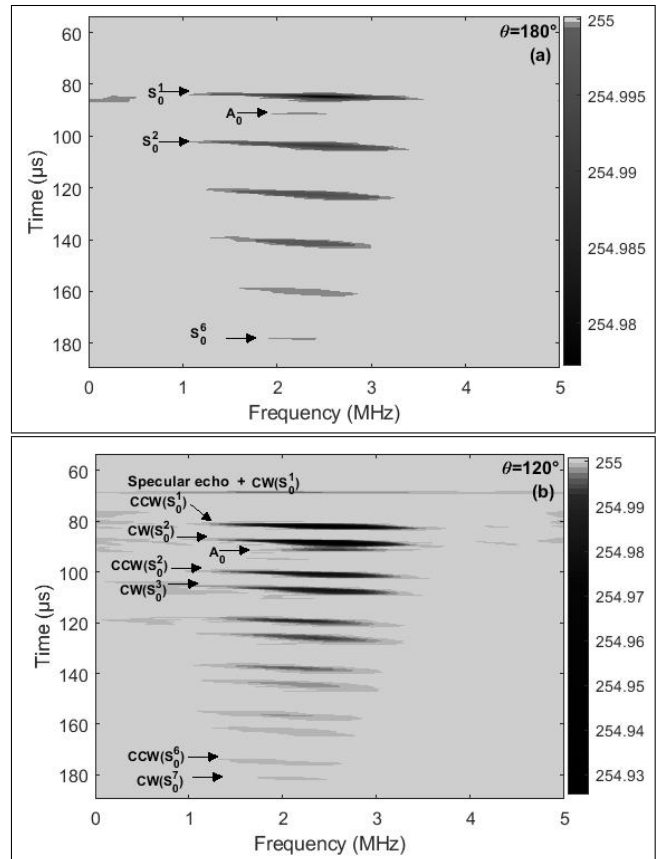


Figure 4. Time-frequency images, (a) is obtained in monostatic configuration ($\theta = 180^\circ$) and (b) is obtained in bistatic configuration ($\theta = 120^\circ$).

4. CONCLUSION

This paper was concerned with the comparison between the monostatic and bistatic configurations. The presented results show that the complete resonance spectrum can be obtained in monostatic configuration. However, in bistatic configuration, it is difficult to detect different resonant frequencies. The application of the SPWV technique on the bistatic experimental signal allows to depict with good precision the clockwise and counterclockwise waves.

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