UNDERWATER ACOUSTIC RADIATION FROM PARTIALLY IMMERSED CYLINDRICAL SHELLS

Daher Diab, Fernand Leon, Farid Chati, Simon Marcellin, Dominique Décultot

Laboratoire Ondes et Milieux Complexes, LOMC UMR CNRS 6294, Normandie Université, Université Le Havre, 75 rue Bellot, 76600, Le Havre, France

Email: daher.diab@univ-lehavre.fr

Abstract: *The purpose of this work is to study the underwater acoustic radiation from a set of partially immersed cylindrical shells in water. First, the vibratory behavior of a stainless steel tube subject to an axial excitation on its emerged section is studied, numerically and experimentally; in the frequency range 20 kHz - 150 kHz. The identification of waves propagating along this tube is realized from a 2D finite element model developed using COMSOL Multiphysics code. The identified waves are the antisymmetric Lamb wave (A_0), the symmetric Lamb wave (S_0) and the Scholte Stoneley wave (A). A good agreement between numerical and experimental results is observed.*

The second part of this paper deals with the sound pressure radiated in water by partially immersed tubes. Two geometric configurations are studied: one tube or two tubes subject to axial excitation on the emerged tube section. In each case, a 3D finite element model is developed and implemented using COMSOL Multiphysics code. These ones enable us to determine the acoustic pressure (resonance spectra) radiated in water from each configuration in an azimuthal plane. In order to validate the numerical model, measurements have been realized in a large tank filled with water for the two distinct geometric configurations. The considered frequency band is between 10 kHz and 120 kHz. The resonance spectra show a good agreement between the numerical and experimental results.

Keywords: *Underwater acoustic radiation, partially immersed tubes, waves propagating in tube, finite element model, experimental measurements*

1. INTRODUCTION

The assessment of sound pressure generated by submerged structures is part of problems regarding underwater noise pollution. The growing number of offshore constructions related to energy generation by wind farms and the regulations on underwater noise pollution increase the importance of these studies [1-4]. Therefore, it becomes important to understand the physical mechanisms responsible for the radiation of a set of wind turbines towers. The object of this first work is the study of underwater acoustic radiation of vibrations of two tubes. This paper focuses on the acoustic radiation of two tubes of 38 mm in diameter. Experimentally, these tubes are immersed vertically in a large water tank (6mx4mx3m). The vibrations are emitted from a contact transducer generating a longitudinal wave on the emerged extremity of each tube. The studied frequency band is between 10 kHz and 120 kHz.

The acoustic radiation of a submerged structure is an important research field of underwater acoustic engineering. The study of the acoustic scattering by a single cylinder or tube excited perpendicular to its axis has been subject of theoretical [5-6] and experimental [7-8] works. The object of the present work is the study of underwater acoustic radiation from partially immersed tubes subject to an axial excitation.

2. IDENTIFICATION OF VIBRATION MODES

Beforehand, we identify the different wave types generated along one tube subject to an axial excitation. The stainless steel tube has the following geometrical and mechanical characteristics: 3 m of length, outer and inner radii of 19 mm and 17.5 mm respectively, density of 8027 kg/m^3, 212 GPa of Young's modulus, Poisson coefficient of 0.28, velocities of the longitudinal and transversal waves of 5823 m/s and 3210 m/s respectively.

2.1. Radial displacements of the tube

A 2D axisymmetric finite element model is developed using COMSOL Multiphysics code. This model allows to determine the radial displacements along the tube which is placed in air and then in water (Fig. 1).

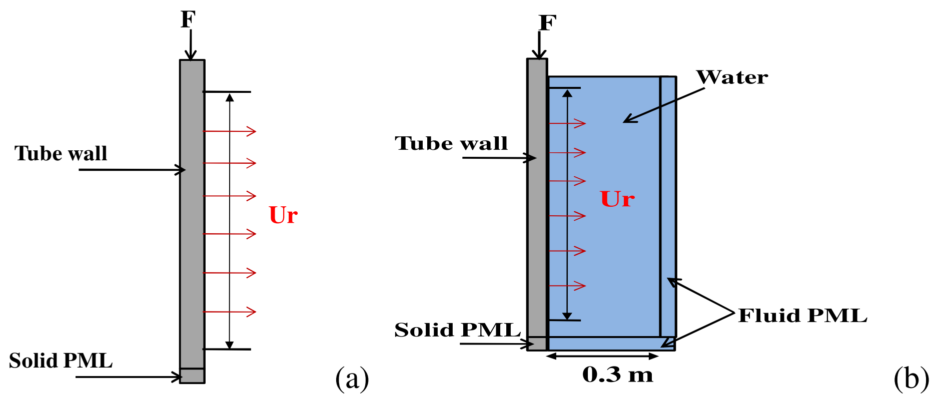


Fig.1: 2D axisymmetric model for the tube: (a) in air and (b) in water

A tube of length 1 m is used, and excited by a force F perpendicular to its top edge section. A Perfecty Matched Layer (PML) is defined to eliminate the reflected echoes from the end of the tube and the water boundaries. Studies are achieved in frequency domain between 20 kHz and 150 kHz and the radial displacement along the tube (0.6 m) is computed and recorded with a space step of 0.2 mm. Then, a 1D spatial Fourier transform is applied on the radial displacement in order to plot the wave vector k versus frequency (Fig. 2) [9].

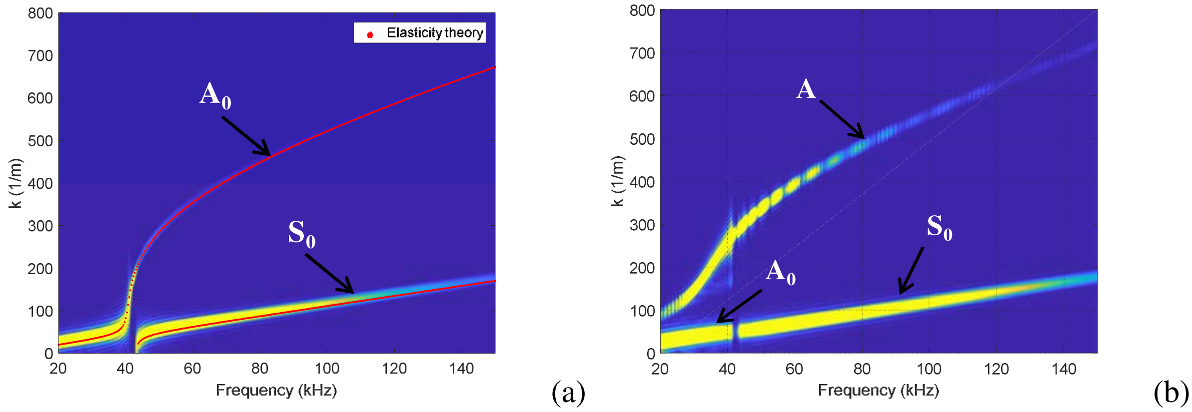


Fig. 2: Wave number dispersion curves of the tube: (a) in air and (b) in water

Fig. 2a shows the two waves generated in air denoted S_0 and A_0 which correspond to the fundamental mode (n = 0). S_0 is a compression wave named symmetric Lamb wave that appears at the ring frequency (45 kHz). At high frequency, its phase velocity tends to the plate velocity (5356 m/s). A_0 is a flexural wave named antisymmetric Lamb wave. At low frequency, the A_0 wave phase velocity tends to the bar velocity (5139 m/s), and tends to the Rayleigh wave velocity (2890 m/s) in higher frequency. These results are validated by analytical results from the theory of elasticity (red curve); a good agreement is obtained between the two cases.

When the cylindrical is immersed in water, the phase velocity of the flexural wave is modified and a new wave appears, the A wave or Scholte Stoneley wave (Fig. 2b). This wave radiates a weak energy in water and its phase velocity tends to the sound velocity in water.

2.2. Acoustic pressure radiated in water

From the 2D finite element model already presented, the sound pressure is determined vertically in the water along the tube length (0.4 m) (Fig 3a). Then, the numerical vibration modes radiating in water are determined by a 2D spatial Fourier transform applied on the pressure. For the experimental set-up (Fig 3b), the stainless steel tube is partially immersed in a large tank filled with water (6mx4mx3m) and excited by a fixed transducer (emitter) on the top edge section. An impulse measurement method is used in this experimental study [10], the emitter emits a short pulse with a broadband frequency.

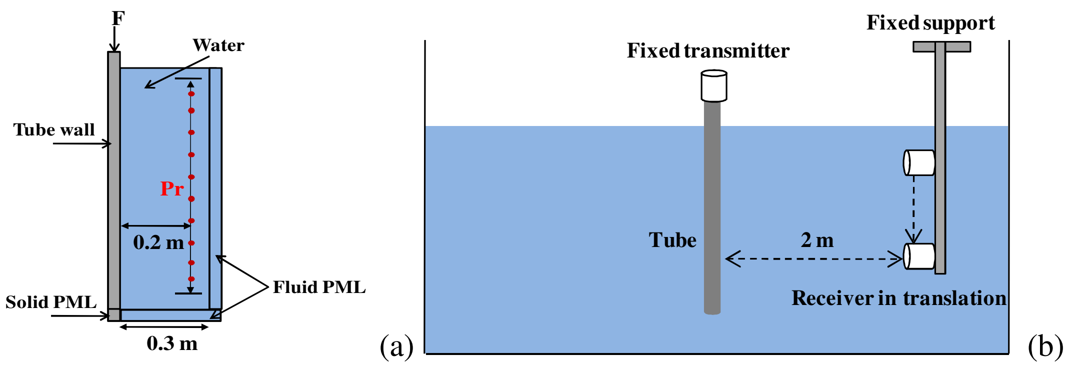
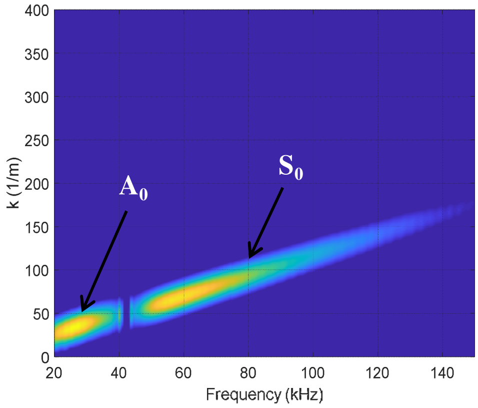
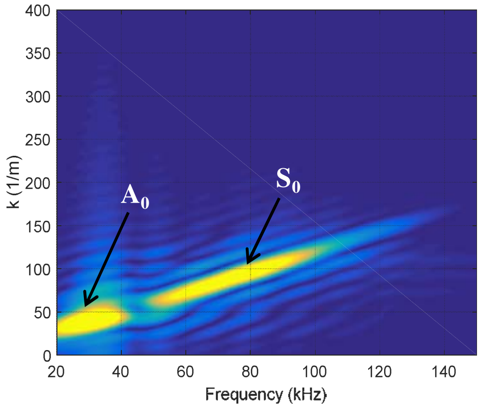


Fig. 3: Numerical model (a) and experimental set-up (b) of the acoustic pressure measurements

A second transducer achieves the measurement of the pressure radiated in water by the tube. These transducers are characterized by a central frequency of 100 kHz. The vertical displacement of the receiver enables us to record the time signals of the pressure radiated along the tube with a step of 1 mm. Then, the waves radiated in water are identified via a 2D Fourier transform of these signals. The experiment results are presented in Fig.4b. A good agreement is noted between the experimental (b) and numerical (a) results; The S_0 and A_0 waves are observed while the A wave does not radiate in water.



(a)



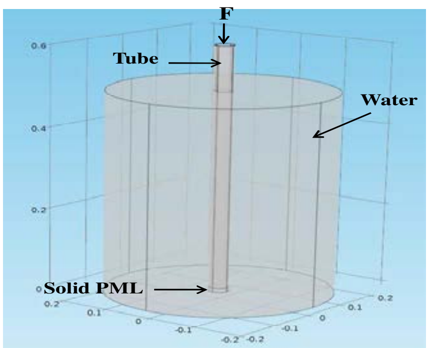
(b)

Fig. 4: Vibration modes radiating in water: (a) Numerical and (b) Experimental

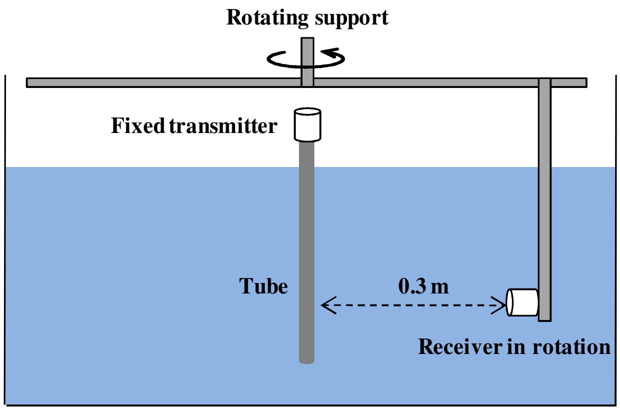
3. RESONANCE SPECTRUM

3.1. One tube configuration

Fig. 5a shows the 3D geometry model of a partially immersed tube. This model is achieved using predefined multi-physics coupling for Acoustic-Solid Interaction in the case of a transient analysis. Fluid medium is defined by a water tube of radius 0.2 m and a length 0.5 m. A solid Perfectly Matched Layer having 10 mm of thickness is placed at the low extremity of the tube (tube length of 0.6 m). In this transient study, the fluid PML is not applicable. A mesh size of λ/4 is used on the tube and λ/3 in water for a frequency of 50 kHz. Then, a very short axial impulse force (F) is applied perpendicular to the total emerged tube section. The experimental set-up (Fig. 5b) is the one presented in §2.2; the immersion transducer rotates around the tube in an azimuthal plane perpendicular to the object axis.



(a)



(b)

Fig. 5: 3D finite element model (a) and experimental set-up (b) of one tube configuration

Numerically and experimentally, the acoustic pressure has been calculated between 0 and 180° for an angular step of 1°. Then, the resonance spectra are obtained from a Fourier transform of each time signal recorded at a given azimuthal angle. The high amplitudes appear in the form of two broad and yellow lines in Fig. 6a. The first around 20 kHz corresponds to an A_0 mode wave and the second around 60 kHz is a S_0 mode wave. At these frequencies, the magnitude varies few according to the angle; this is a breathing mode of the tube (n = 0). The experimental spectrum (Fig. 6b) shows a good agreement with the numerical results. The experimental characteristic frequencies are 25 kHz and 65 kHz. This agreement validates our 3D finite element model.

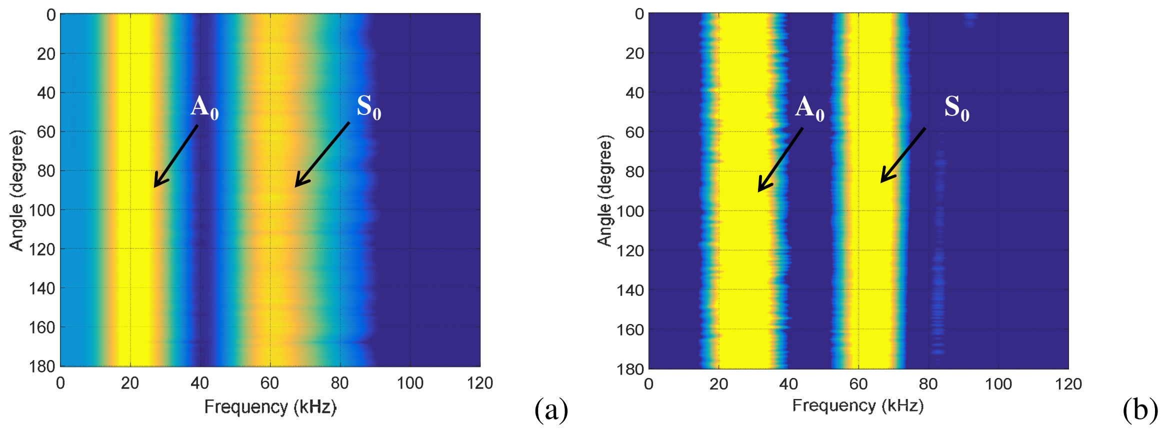


Fig. 6: Resonance spectrum of one tube configuration: (a) Numerical and (b) Experimental

3.2. Two tubes configuration

In the numerical model, the axes of these tubes are displaced forward and backward respectively by 2a relative to the central axis of rotation (Fig.7a). In this case, the distance between the axis of the tubes is d = 4a (a is the outer radius of the tube). A very short axial impulse F on the emerged tube sections excites these tubes. Experimentally (Fig.7b), a transducer excites the upper section of each tube. The signal applied to these transducers is identical.

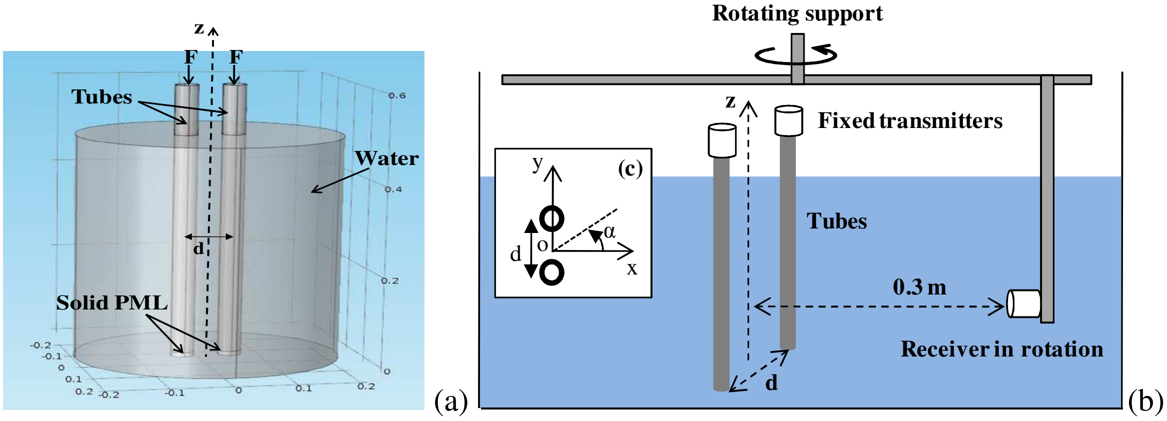


Fig. 7: 3D finite element model (a) and experimental set-up (b) of two tubes configuration, (c) Top view

A Fourier transform is applied on each time signal recorded at a given azimuthal angle α. The set of resonance spectra is assembled to obtain the figure 8. On Fig. 8a, the resonance frequencies are always around 20 kHz and 60 kHz by comparison with the one tube configuration (Fig. 6a). Nevertheless, regular spots appear according to the observation angle of the receiving transducer. The experimental results (Fig.8b) validate this numerical model; the resonance spectra are in good agreement with the numerical spectra.

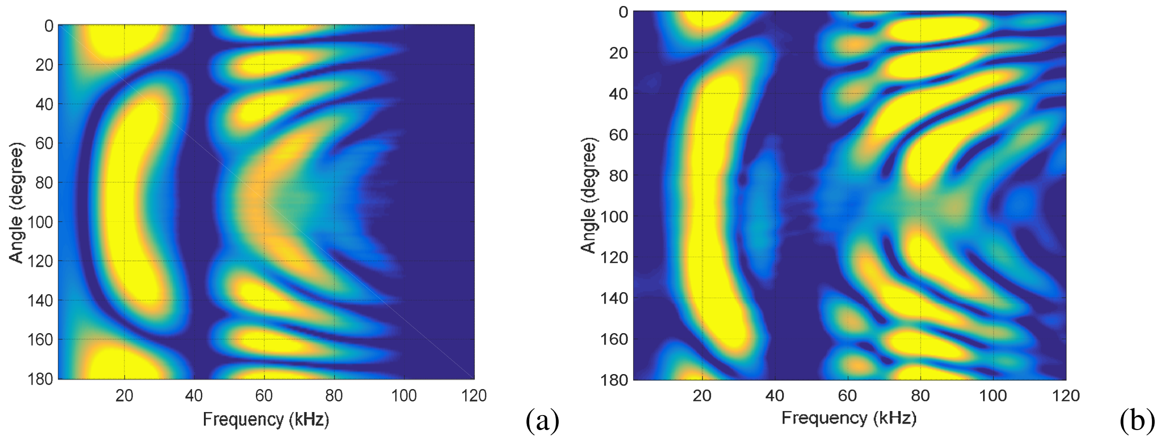


Fig. 8: Resonance spectrum of two tubes configuration: (a) Numerical and (b) Experimental

Fig. 9 shows the numerical resonance spectrum for three angles: 0°, 45° and 90°. As shown in Fig. 9b, at α = 0°, the two tubes configuration enables us to obtain a spectrum similar to that of one tube configuration (Fig. 9a). For this angle, the two tubes form two synchronous sources in phase. For α =45°, a doubling of resonance is obtained which is due to the path difference between the two radiated signals. Finally, at α = 90° we do not see the duplication of resonance. In this case, one tube is hidden by the other. The result is the spectrum of a single tube.

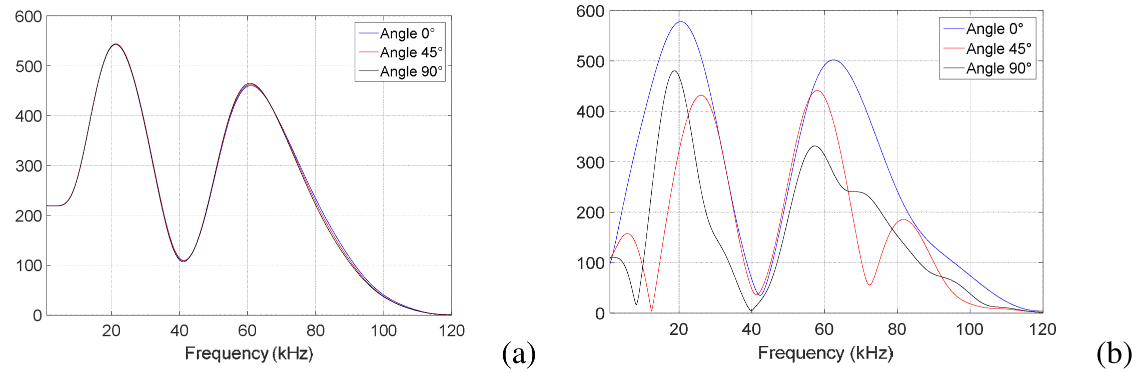


Fig. 9: Numerical resonance spectrum for three angles: one tube (a) and two tubes (b) configurations

4. CONCLUSION

In this work, firstly we presented a 2D finite element model and an experimental set-up used to identify the vibration modes of a stainless steel tube subject to an axial excitation. These studies are realized in air or in water. The identified waves are the antisymmetric Lamb wave (A_0), the symmetric Lamb wave (S_0) and the Scholte Stoneley wave (A).

Secondly, the acoustic pressure radiated in water by partially immersed tubes has been studied using two geometric configurations: one tube and two tubes. A 3D finite element model of partially submerged cylindrical shells is built for each configuration to predict the radiated sound pressure. Then, these numerical models are validated by measurements using two distinct geometric configurations. The resonance spectra show a good agreement between the numerical and experimental results.

5. ACKNOWLEDGEMENTS

This work is supported by Région Normandie.

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