Sound radiation from a cylindrical shell with an acoustic coating

Cikai Lin (1), Gyani Shankar Sharma (1), Alex Skvortsov (2), Ian MacGillivray (2), Nicole Kessissoglou (1)

(1) School of Mechanical and Manufacturing Engineering, UNSW Sydney, Sydney, Australia
(2) Maritime Division, Defence Science and Technology Group, Melbourne, Australia

ABSTRACT

Sound radiation from a submerged, structurally excited, cylindrical shell with an acoustic coating applied to the external shell surface is presented. The coating is composed of a soft elastic medium embedded with a circumferential array of periodic resonant inclusions. The layer of soft material encompassing the resonant inclusions is approximated as a homogeneous medium with effective material and geometric properties. Results show that local resonance of inclusions leads to sound reduction in a broad frequency range. The effects of variation in the size and number of resonant inclusions on the radiated pressure of the submerged cylindrical shell are observed.

1 INTRODUCTION

Acoustic coatings on the wetted surface of marine vessels are favourable candidates for mitigation of underwater noise. Acoustic coatings are generally designed using metamaterials, which are artificially engineered composites comprising soft elastic media embedded with resonant inclusions. Physical mechanisms governing acoustic performance are attributed to local resonances of the inclusions, leading to effective conversion of longitudinal to shear waves which are subsequently dissipated due to high shear damping of the soft material (Ivansson, 2012). Previous work on acoustic coatings have primarily focused on planar arrays of resonant inclusions in elastic media, with or without a rigid backing (Leroy et al, 2009; Sharma et al, 2017, 2019). This work considers a cylindrical shell submerged in water and covered by an acoustic coating composed of a circumferential array of voids.

2 METHODOLOGY

Figure 1(a) presents a two-dimensional cylindrical shell coated with a soft elastic medium. A circumferential array of cylindrical voids is embedded in the centre of the coating. The cylindrical shell is modelled using Donnell-Mushitari theory with a modifying operator by Flügge-Byrne-Lur'ye (Leissa, 1993). The coating material is a soft elastic medium with an impedance similar to that of water. The layer of soft material embedded with resonant inclusions is modelled as a homogenised layer, as shown in Fig. 1(b).

Effective properties of the homogenised medium have been previously derived, whereby Morse and Ingard (1968) derived an expression for the effective thickness and Wu et al. (2007) derived expressions for the effective material properties. The cylindrical shell is coupled to the acoustic coating by satisfying kinematic conditions between the exterior and interior of the shell and coating surfaces. The shell is submerged in water and has a vacuous interior cavity.

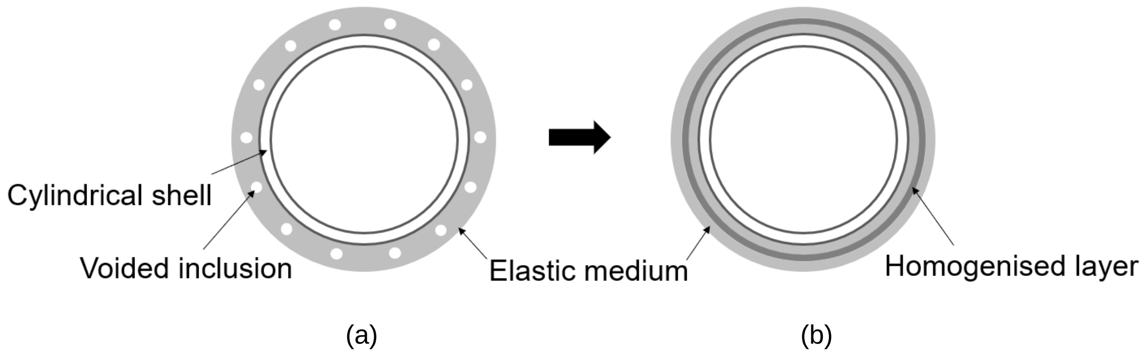

Figure 1: Schematic diagram of an infinite cylindrical shell covered by an acoustic coating with (a) periodic voided inclusions and (b) homogenised layer

3 RESULTS AND DISCUSSION

The cylindrical shell is made of steel of density 7800 kg/m^3, longitudinal modulus 173-3.5i GPa and shear modulus 80.77-1.6i GPa. The elastic medium of the acoustic coating has density 1000 kg/m^3, longitudinal modulus 1-0.01i GPa and shear modulus 0.009-0.0027i GPa. The shell has a mean radius of 1m and the thickness of the coating is 0.1 m. A structural line force is applied to the interior surface of the shell. The radiated sound pressure is calculated at a radial distance of 5 m from the shell in the opposite direction of the force.

Figures 2 and 3 present the radiated acoustic pressure for a bare shell and a coated shell for variation in void diameter (Fig. 2) and variation in the number of voids (Fig. 3). The monopole resonance frequency of the circumferential array of voids is indicated by a circle. Broadband sound reduction can be observed near the monopole resonance of voids. Increasing the size of voids leads to higher monopole resonance frequency and greater reduction in radiated pressure around monopole resonance. Increasing the number of voids also results in an increase in the monopole resonance frequency and greater reduction in radiated sound around monopole resonance. The introduction of a low frequency peak for the coated shell corresponds to spring-mass resonance of the system, whereby the coating behaves as a spring and the mass is contributed by the shell. The frequency of spring-mass resonance decreases as the diameter or number of voids increases.

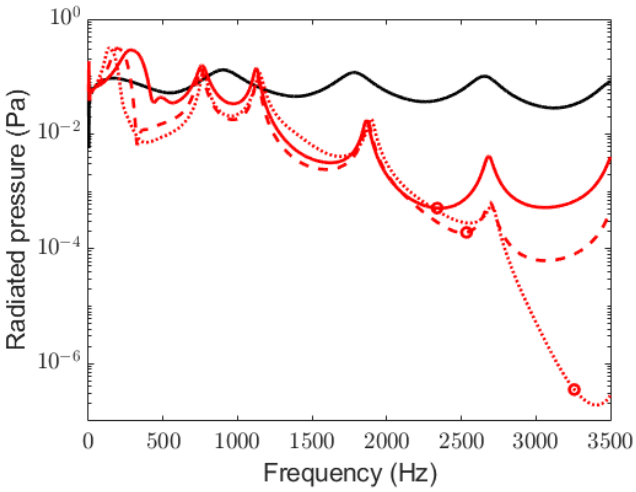

Figure 2: Radiated sound pressure in Pascal from an uncoated shell (black line) and a coated shell with 50 voids of diameter of 5cm (solid red line), 7cm (dashed red line) and 9cm (dotted red line). The monopole resonance is indicated by a circle

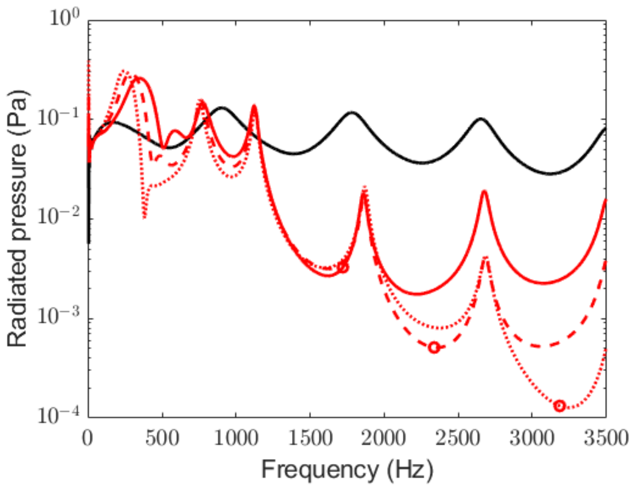

Figure 3: Radiated sound pressure in Pascal from an uncoated shell (black line) and a coated shell with number of voids of 35 (solid red line), 50 (dashed red line) and 65 (dotted red line). The monopole resonance is indicated by a circle

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