Results in Physics 11 (2018) 315–324

Contents lists available at ScienceDirect

Results in Physics

journal homepage: www.elsevier.com/locate/rinp

Experiment and modeling of vibro-acoustic response of a stiffened submerged cylindrical shell with force and acoustic excitation

Xianzhong Wang[a,b,*], Di Chen[b], Yeping Xiong[c], Quanzhou Jiang[b], Yingying Zuo[b]

[a] Key Laboratory of High Performance Ship Technology (Wuhan University of Technology), Ministry of Education, Wuhan 430063, PR China
[b] Departments of Naval Architecture, Ocean and Structural Engineering, School of Transportation, Wuhan University of Technology, Wuhan 430063, PR China
[c] Faculty of Engineering and the Environment, University of Southampton, Southampton SO17 1BJ, United Kingdom

ARTICLE INFO

Keywords:
A ring-stiffened cylindrical shell
Force excitation
Acoustic excitation
Experiment

ABSTRACT

Taken a submerged ring-stiffened cylindrical shell as an experimental model, the experimental studies was investigated to study the effects of force and acoustic excitation on the vibro-acoustic response of the cylindrical shell. A precise transfer matrix method (PTMM) was presented to compare the shell vibration and sound radiation of the submerged stiffened cylindrical shell with the experimental results. The result shows that results from PTMM are in good agreement with the experimental results. It shows that the PTMM is reliable and the result from PTMM is credible. The vibration acceleration response of the water case has less peak numbers and the value is less than that of the air case. The peak value of sound pressure in the force excitation case is relate to structural natural frequency. The peak value of sound pressure in the acoustic excitation case is relate to structural natural frequency and internal cavity natural frequency.

Introduction

Ring-stiffened cylindrical shells are the typical structural forms in aeronautical or naval industry. There is a considerable amount of literature dealing with the vibration and sound radiation of stiffened cylindrical shells and much attention on the dynamic behaviors of cylindrical shell has been received [1–5]. Some theoretical methods have been developed on the dynamic behaviors of shells, such as wave propagation method [6,7], Fourier spectral element method [8,9], transfer matrix method [10] and so on.

Analytical solutions are hard to be derived with the presence of the fluid load and discontinuities of the stiffened shell. Then semi analytical methods and numerical approach are employed to model the addressed problem. Caresta and Kessissoglou [11–13] used the wave propagation method to solve the structure response and acoustic radiation characteristics of underwater ring stiffened cylindrical shell under axial excitation. They paid more attention on the structural and acoustic of a submarine hull considering effect of propeller forces and harmonic excitation. Meyer et al. [14] had a research on the prediction of the vibro-acoustic behavior of submerged shells with non-axisymmetric internal structures. Wang et al. [15–17] developed a precise transfer matrix method for vibro-acoustic analysis of submerged stiffened combined shell and conical shell by solving a set of first order differential equations. Qu et al. [18–20] presented a modified variational method for free and forced vibration analysis of ring-stiffened conical-cylindrical and conical-cylindrical-spherical shells subjected to different boundary conditions, and used the discrete element stiffener theory to consider the ring-stiffening effects.

Numerical method such as finite element method (FEM) and boundary element method (BEM) have the advantages to model vibro-acoustic behavior of arbitrary complex structure, but actually the development of FEM and BEM is limited by many problems. Based on the discrete element meshes and constructing the low order shape functions to solve the fluid-structure interaction problem, its solution accuracy is restricted by frequency band. The number of elements will increase sharply as the frequency increases, which seriously reduces computational efficiency and increases storage space. Ettouney et al. [21] investigated vibrational and acoustical characteristics of a submerged cylindrical shell with two hemispherical end closures and an interior beam. A finite difference method was adopted to model the shell and the beam was tackled using FEM. Marcus [22] performed A finite element analysis on a submerged cylindrical shell with internal frames and point masses attached to the frames. A point force on the shell is shown to excite resonances of the frames. A fully coupled finite element/boundary element (FE/BE) model has been developed to investigate the effect of mass distribution and isolation in a submerged hull [23].

* Corresponding author at: Departments of Naval Architecture, Ocean and Structural Engineering, School of Transportation, Wuhan University of Technology, Wuhan 430063, PR China.
E-mail address: xianzhongwang00@163.com (X. Wang).

https://doi.org/10.1016/j.rinp.2018.09.017
Received 18 July 2018; Received in revised form 16 August 2018; Accepted 7 September 2018
Available online 13 September 2018
2211-3797/

Meyer et al. [24] developed the Condensed Transfer Functions (CTF) method to study vibrations and acoustics of cylindrical shells with more complicated interior frames. Chen et al. [25,26] developed a hybrid approach combining WBM and FEM is presented to investigate vibration characteristics of a cylindrical shell coupled with interior structures.

Due to the operation of internal machinery and equipment, radiation noise of cylindrical shells is generated by two kinds of motivation: force excitation and acoustic excitation. To the authors' knowledge, there are some but not many literature concerning vibro-acoustic behavior of stiffened cylindrical shells with force and acoustic excitation. Farshidianfar et al. [27] used two other methods along with was to excite a long circular cylindrical shell, with acoustical excitation and simply supported boundary conditions.

The aim of the present work is to discuss experimental results of a stiffened cylindrical shell with force and acoustic excitation. The authors setup the experiment model and ran the model test to free vibration, forced vibration and acoustic response of the cylindrical shell in fluid. The authors also employ precise transfer matrix method (PTMM) [15] to solve the first order differential equations for modelling vibro-acoustic behavior of the stiffened submerged cylindrical shell. The vibration of the cylindrical shell is obtained by assembling the segment field transfer matrixes of the cylindrical shell and point transfer matrixes of the ring-stiffener. Based on Moore-Penrose pseudoinverse method, the radiated noise of the cylindrical shell can be solved by taking collocation points on the fluid-structure interaction interface. Then the calculated results are compared with the experimental results. Also, the effect of the external excitation on the acoustic response of the cylindrical shell is investigated.

Experimental research

Experimental model

The test model is a single ring-stiffened cylindrical shell, as shown in Fig. 1. Welding was not considered to guarantee the accordance with the theoretical model. The cylindrical shell has the following material properties: Length $L = 0.8\,\text{m}$, Radius $R_1 = 0.3\,\text{m}$. Shell thickness $t = 4\,\text{mm}$. sectional dimensions of the stiffener is 40 mm × 4 mm. The stiffeners spacing $\Delta l = 0.16\,\text{m}$. The density of the material $\rho = 7850\,\text{kg/m}^3$, the elastic modulus of the material $E = 203\,\text{GPa}$ and the Poisson's ratio $\nu = 0.3$. 15 mm thick caps are screwed at the ends of the cylinder. This stiffened cylindrical shell is referred to as the axisymmetric case, which is equipped with a fixed exciter and primary sound source. The function of the external hoisting model is achieved by welding the lifting lug at the end cover.

Experimental setup

The cylindrical shell vibration measurement system is mainly composed of anechoic tank, vibration exciter, hammer, power amplifier, signal generator, data acquisition device, force sensor, acceleration sensor and hydrophone. The anechoic tank is 8 m long, 4 m wide and 3 m deep. The cuneiform sound absorption cone is arranged on the six surface of the pool, anechoic tank and test model are shown in Fig. 2.

A 10 mm diameter patch is glued on the inner surface of the cylindrical shell, and screwed to a shaker (DH-40020). The shaker is fixed on the end cap in order to excite the point of coordinate $(x, r, \theta) = (0.4\,\text{m}, 0.3\,\text{m}, 0)$ in the cylindrical system (with $x = 0$ at the bottom of the cylindrical shell). The measurement excitation is 1 N sinusoidal excitation. There are two components between the patch and the shaker: an impedance head (PCB-208c02) that measures acceleration and force at the excitation point, and a threaded rod that allows assuming a radial excitation in the cylindrical system. A flexible rope is used to connect the shop crane above the anechoic tank, and the heavy load is laid on the top cover of the model to keep balance. There are 8 acceleration sensors (PCB-352c03) to measure the radial vibration acceleration on the outer surface of the cylindrical shell for the four configurations, which include free vibration and forced vibration in air and fluid. Taking account of axisymmetric features, several measuring points along the axial and circumferential direction are arranged to record the vibration responses. The positions of 8 sensors are located at position1 (0.4 m, 0.3 m, 0), position2 (0.48 m, 0.3 m, 0), position3 (0.56 m, 0.3 m, 0), position4 (0.64 m, 0.3 m, 0), position5 (0.72 m, 0.3 m, 0), position6 (0.4 m, 0.3 m, π/4), position7 (0.4 m, 0.3 m, π/2), position8 (0.4 m, 0.3 m, π). The layout of measuring points is shown as Fig. 2.

PTMM for stiffened cylindrical shell

Field transfer matrix for the cylindrical shell

A schematic diagram of the stiffened cylindrical shell is shown in Fig. 3. h denotes the thickness of the cylindrical shell, L denotes the length of the cylindrical shell, and R denotes the radius of the cylindrical shell. Based on Flügge shell theory, it can be written as a matrix differential equation [15]

$$\frac{d\boldsymbol{Z}(\xi)}{d\xi} = \mathbf{U}(\xi)\boldsymbol{Z}(\xi) + \boldsymbol{F}(\xi) - \boldsymbol{p}(\xi) \tag{1}$$

where $\boldsymbol{Z}(\xi) = \{u_* \; v_* \; w_* \; \psi_* \; M_{s^*} \; V_{s^*} \; S_{s\theta^*} \; N_{s^*}\}^{\mathrm{T}}$, u_*, v_*, w_*, ψ_*, M_{s^*}, V_{s^*}, $S_{s\theta^*}$ andN_{s^*} are the dimensionless axial, circumferential, radial displacements, angular angle, moment, radial, circumferential and axial forces. $\mathbf{U}(\xi)$ is the field transfer matrix for the state vector of the cylindrical shell. ξ is the dimensionless axial position. The nonzero elements in

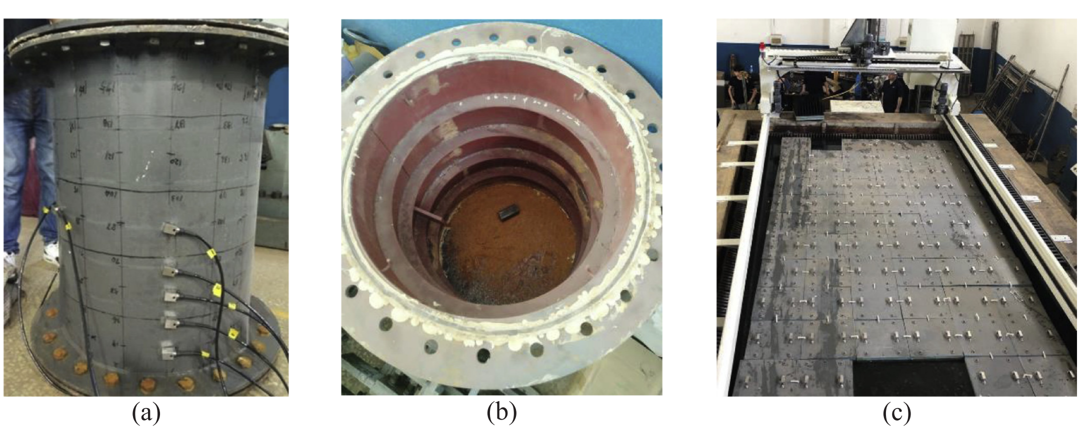

Fig. 1. Pictures of an axisymmetric stiffened cylindrical shell: (a) hanged on a rope and (b) interior view. (c) anechoic tank with a running gear.