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Input power flow in a submerged infinite cylindrical shell with doubly periodic supports

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Abstract

A submerged cylindrical shell reinforced by supports of rings and bulkheads is the primary structure of submarine, torpedo and all kinds of submerged aircrafts, so it is significant to study its characteristics of structure-borne sound. By means of periodic structure theory, the input power flow from a cosine harmonic line force into a submerged infinite cylindrical shell, reinforced by doubly periodic supports of rings and bulkheads, is studied analytically. The harmonic motion of the shell and the sound pressure field in the fluid are described by Flügge shell equations and Helmholtz equation, respectively. Since the fluid radical velocity and the shell radical velocity must be equal at the interface of the outer shell wall and the fluid, the motion equations of this coupled system are obtained. Both four kinds of forces (moments) between rings and shell and four kinds of forces (moments) between bulkheads and shell are considered. The solution is obtained in series form by expanding the system responses in terms of the space harmonics of the spacings of both stiffeners and bulkheads. The input vibrational power flow into the structure is obtained and the influences of different structural parameters on the results are analyzed. The analytic model is close to engineering practice, and it will give some guidelines for noise reduction of this kind of shell.

Keywords: Submerged cylindrical shell; Rings; Bulkheads; Periodic structures; Space harmonic analysis method; Input power flow

1. Introduction

A submerged cylindrical shell reinforced by supports of rings and bulkheads is the primary structure of submarine, torpedo and all kinds of submerged aircrafts, so it is significant to study its characteristics of structure-borne sound.

Periodic structures of uniform plates and shells with identical stiffeners at regular interval have been studied by several investigators [1–9]. Various methods are used to research the vibration of these structures, such as receptance methods, transfer matrices, direct solutions of the wave equation, space harmonic analysis, energy method, Rayleigh–Ritz method, the finite element method and the method of combining Green's matrix with the boundary integral equation, etc. In these works, the characteristics of both freely propagating wave motion and the forced wave motion have been deliberately computed. Propagation zones and attenuation zones were found as a special characteristic of these periodic structures.

Among the numerous studies on periodic structures, little was mentioned about doubly periodic supports. Burroughs [10] studied the fluid-loaded infinite circular cylindrical with doubly periodic ring supports forced by a point excitation and gave the analytical expression of far field acoustic radiation, which established the basal thought of this kind of problem. But the model he used was comparatively simple, only the normal force between the stiffeners and the shell was considered.

The process of structural vibration is actually the process of wave transmission, but the existing of internal structure will disturb wave transmission. Guo [11] studied sound scattering from cylindrical shell with internal bulkheads. Fourier transformation and angular harmonics

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decomposition were used to derive solutions in terms of coupling forces and bending moments at the attachment. Both monostatic and bistatic acoustic field were examined to reveal the characteristics of the scattering. Guo [12] further studied sound radiation from cylindrical shell attached by an internal elastic plate along its axial direction. The result indicated that the internal structure has an important influence on the sound radiation, and the coupling between the shell and the internal plate brings flexural waves into radiation process. Moreover, it has been shown that resonances of the internal plate manifest themselves in the far-field radiation as sharp spectral peaks while resonances of the shell as deep dips. Though both analytic models adopted by Guo were unstiffened cylindrical shell with internal plate, his work emphasized on discovering the regularities. Xie et al. [13] investigated sound radiation from fluid-loaded infinite cylindrical shell with rings, bulkheads and longitudinal stiffeners. Combined Fourier transform with modal expansion, the shell's vibration response and acoustic radiation were formulated. He found transverse bulkheads will increase radiation pressure of the cylindrical shell and the spacing of bulkheads will have little influence at a relatively high frequency.

Since Goyder and White [14–16] first definitely presented the concept of power flow, vibrational power flow has become a valuable tool in the analysis of noise and vibration. Without considering the influence of stiffeners, Fuller [17] investigated the forced input mobility of an infinite elastic circular cylindrical shell filled with fluid. The spectral equations of motion of the shell-fluid system and the method of residues were employed to evaluate the mobility, and their physical interpretation was also discussed. Zhang and Zhang [6] introduced the concept of power flow into the analysis of periodic shells, and studied the input vibrational power flow from a cosine harmonic circumferential line force and the power transmitted by internal forces of the shell wall *in vacuo*.

When periodic structure is connected with the fluid field, space harmonic analysis method presented by Mead and Pujara [2] has been widely used. In the past thirty years, Mead and his collaborators made a great deal contributions on periodic beam, periodic plate and periodic shell by using space harmonic analysis method, and their works were well summarized in Ref. [5]. Xu et al. [7] used this method to study the input power flow in a periodically stiffened fluid-filled cylindrical shell. Lee and Kim [8] combined space harmonic analysis method with the virtual energy method to study an infinite stiffened cylindrical shell subjected to a plane wave incidence. The authors [18,19] also used this method to study the characteristics of the vibrational power flow propagation and sound radiation in an infinite submerged periodic ring-stiffened cylindrical shell. It is proved space harmonic analysis is an effective approach to dispose periodic element and fluid field in the coupled system.

In this paper, space harmonic analysis method is extended to analyze the input power flow from a cosine harmonic line force into a submerged infinite cylindrical shell reinforced by doubly periodic supports of rings and bulkheads. The influences of the rings, the bulkheads and that of the outer fluid field upon the elastic cylindrical shell are all considered. In the analysis, the solution is obtained in series form by expanding the system responses in terms of the space harmonics of the spacings of both stiffeners and bulkheads. Moreover, the input vibrational power flow into the structure is given and the influences of the design parameters on the results are also discussed. The analytic model is close to engineering practice, and it will give some guidelines for noise reduction of this land of shell.

2. The response of the coupled system to converted harmonic pressure

A submerged infinite cylindrical shell reinforced by doubly periodic supports of rings and bulkheads shown in Fig. 1 is considered. Supposing the density of the fluid outside is ρ_f and the sound velocity in the fluid is c_f. The shell is characterized by its mean radius a, wall thickness h, mass density ρ_s, Young's modulus E and the Poisson ratio μ. The shell is reinforced ulteriorly by doubly periodic supports of rings and bulkheads. The ring stiffener spacing is l while the bulkhead spacing is l_2. All the connections are supposed as rigid, so that, at each line of attachment, the shell and the stiffener have the same linear velocity and angular velocity. Both the stiffeners and bulkheads may exert radial force, circumferential force, axial force and moments on the shell.

2.1. The motion equations of the cylindrical shell

Flügge shell equations [20] are used to describe the equations of motion of the cylindrical shell in axial, circumferential and transverse directions

$$\left\{a^2\frac{\partial^2}{\partial x^2}+\frac{1-\mu}{2}(1+\beta^2)\frac{\partial^2}{\partial\theta^2}-a^2\frac{1}{c_p^2}\frac{\partial^2}{\partial t^2}\right\}u+\left\{\frac{1+\mu}{2}a\frac{\partial^2}{\partial x\partial\theta}\right\}v$$
$$+\left\{\mu a\frac{\partial}{\partial x}+\beta^2 a\left(\frac{1-\mu}{2}\frac{\partial^3}{\partial x\partial\theta^2}-a^2\frac{\partial^3}{\partial x^3}\right)\right\}w+f_1=0, \tag{1a}$$

$$\left\{\frac{1+\mu}{2}a\frac{\partial^2}{\partial x\partial\theta}\right\}u+\left\{\frac{\partial^2}{\partial\theta^2}+\frac{1-\mu}{2}(1+3\beta^2)a^2\frac{\partial^2}{\partial x^2}-a^2\frac{1}{c_p^2}\frac{\partial^2}{\partial t^2}\right\}v$$

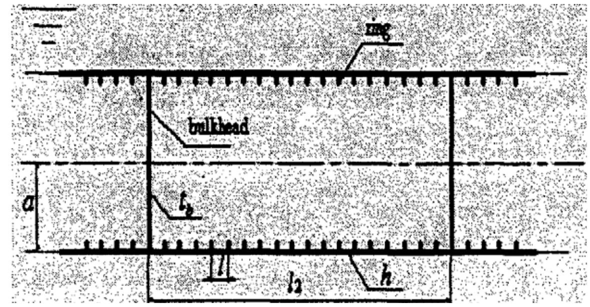

Fig. 1. A submerged infinite cylindrical shell reinforced by doubly periodic supports of rings and bulkheads.