The Numerical Prediction and Features Analysis of Cylindrical Shell Acoustic Radiation Noise

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ABSTRACT

Target feature is important information in underwater target classification. A characteristic analysis in underwater cylindrical shell acoustic radiation noise was studied in this paper based on the finite element/boundary element method (FE/BEM) method. Firstly, the numerical prediction of cylindrical shell acoustic radiation noise based FE/BEM method was verified by the numerical and analytical solutions. The characteristic of acoustic radiation was studied with different cylindrical shell size, material, excitation points, shape, observing position. Simulation results show that the features in acoustic radiation noise were relevant to the medium, radius and shape. The features analysis had some guidance significance with the target identification.

Keywords: cylindrical shell, FE/BEM, acoustic radiation noise
I-INCE Classification of Subjects Number(s): 42

1. INTRODUCTION

Acoustic radiation (1, 2) caused by shell vibration is important in underwater acoustic. The basic structure of the underwater vessel can be approximated as a finitely long cylindrical shell. Theoretical method, numerical simulation method and experimental method are used to study the vibration and acoustic radiation of the finitely long cylindrical shell. Stepanishen and Chen (3) calculated the near-field sound pressure of infinitely and finitely cylindrical shell. More and more scholars focused on the vibration and acoustic radiation of cylindrical shell with ribs and deck structure. Junger (4, 5) and Tang (6) did a great job in this job. Liu (7) analyzed intrinsic mode characteristic in underwater cylindrical shell acoustic radiation through theory method. In previous research, it could be concluded that the underwater shell acoustic radiation is related to various influencing factors, such as radiation source length, radius, thickness, excitation points, and different structure. Therefore, intrinsic features could be found in the underwater shell radiated signals. In recent decades, the numerical simulation method has made an advantage in the computer, and more and more scholars (8, 9) did a great job with FE/BEM method in structure vibration radiation. In the paper, acoustic radiated characteristic of the finitely long cylindrical shell is analyzed by FE/BEM simulation algorithm. The features of the finitely long cylindrical shell corresponding to different structure could be analyzed. From previous research work, it can be concluded that the shell dimension parameters are the main factors in low and middle frequency band, while internal structures, such as ribs and bulkheads are the main factors in high frequency band. The frequency characteristics of the underwater target are concentrated in the middle and low frequencies. In underwater target identification, the feature in low frequency band is important. So the acoustic radiation of the finitely cylindrical shell in low frequency domain is studied in this paper.

2. VIBRATION AND ACOUSTIC RADIATION SIMULATION VERIFICATION OF CYLINDRICAL SHELL BASED ON FE/BEM METHOD

Considering the vibration noise of the closed structure surface s, the Wave Equation can be

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written as

$$\nabla^2 p - \frac{1}{C^2}\frac{\partial^2 p}{\partial t^2} = 0 \tag{1}$$

That is Helmholtz Equation

$$\nabla^2 p + k^2 p = 0 \tag{2}$$

where p is sound pressure, $k = \omega/c$ is wavenumber, ω is circular frequency and c is sound velocity, and S satisfies Neumann boundary condition. p satisfies Sommerfeld radiation condition, such as

$$\lim_{r\to\infty}\left[r\left(\frac{\partial p}{\partial r} - ikp\right)\right] = 0 \tag{3}$$

The free space Green's function of the basic solution of Equation (2) is such as

$$G(Q,P) = \frac{e^{-ikr}}{4\pi r} \tag{4}$$

where $r = |Q-P|$, Q is any point on surface S, and P is any point in the space B.

Form Equaction (4), the Helmholtz Equation can be written as

$$C(P)\,p(P) = \int_S \left[G(Q,P)\frac{\partial p(Q)}{\partial n} - \frac{\partial G(Q,P)}{\partial n}p(Q)\right]dS(Q) \tag{5}$$

where $C(P) = \begin{cases} 1 & P \in B \\ \frac{1}{2} & P \in B \\ 0 & P \notin S \cup B \end{cases}$.

The BEM equation is such as

$$HP = GV_n \tag{6}$$

where P is sound pressure of surface S, V_n is normal velocity of surface S.

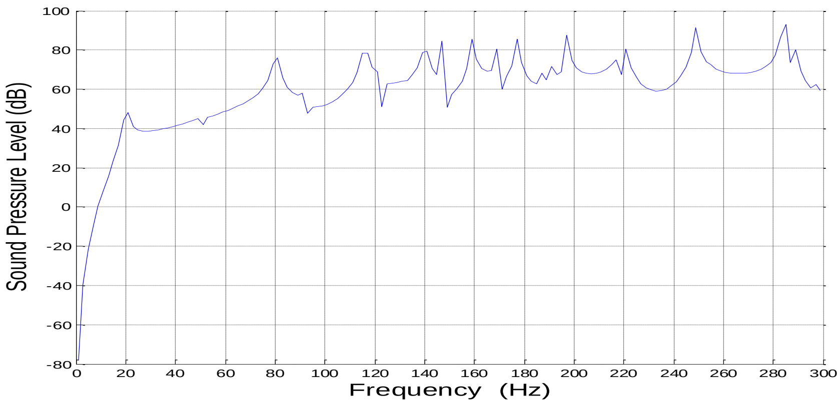
The acoustic radiation power can be written as

$$W = \frac{1}{2}\int_S \mathrm{Re}\left(PV_n^*\right)dS \tag{7}$$

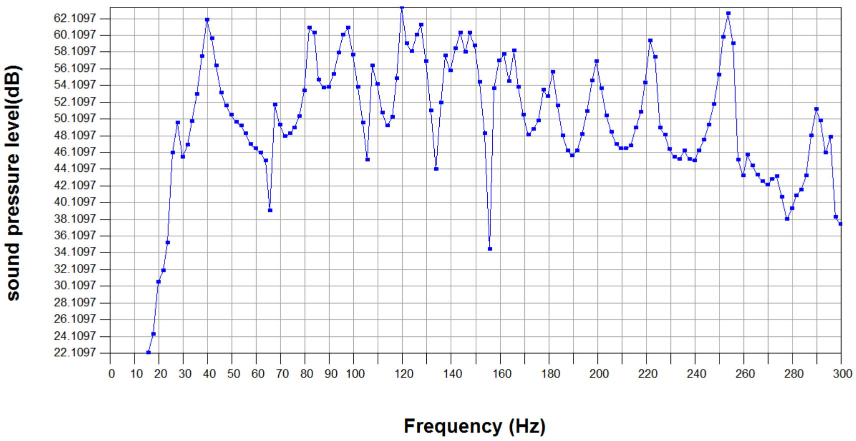
where V_n^* is conjugate complex of V_n, $\mathrm{Re}\left(PV_n^*\right)$ is real part of PV_n^*.

The radiation sound pressure of any point in space B can be saluted from Helmholtz Equation.

Length, radius and other parameters must not be the same for different underwater target. The central axis of the finitely long cylindrical is x. The finitely long cylindrical shell length is 9.3 m, the radius is 3.1 m and the thickness is 0.027m. The density of cylindrical shell is 7800 kg/m3, the propagation velocity of sound in water is 1500 m/s, the Poisson ratio is 0.3, the Young's modulus is 2.1×1011 N/m2, the location of observing point is (0, 100 m, 0), the location of excitation point is (0, 3.1 m, 0), the radius force is 1 N, and the verified frequency from 1 Hz to 300 Hz. The simulation results are shown in Figure 1 using an upper frequency of 300 Hz, where SPL (sound pressure level) of observing point based on the theoretical method result is shown in Figure 1(a), and Figure 1(b) is about the numerical calculation result based on FE/BEM method. From the result, it can be easily seen that the same peak of SPL near 250 Hz. So the FE/BEM method is feasible.



(a) SPL based on theoretical method

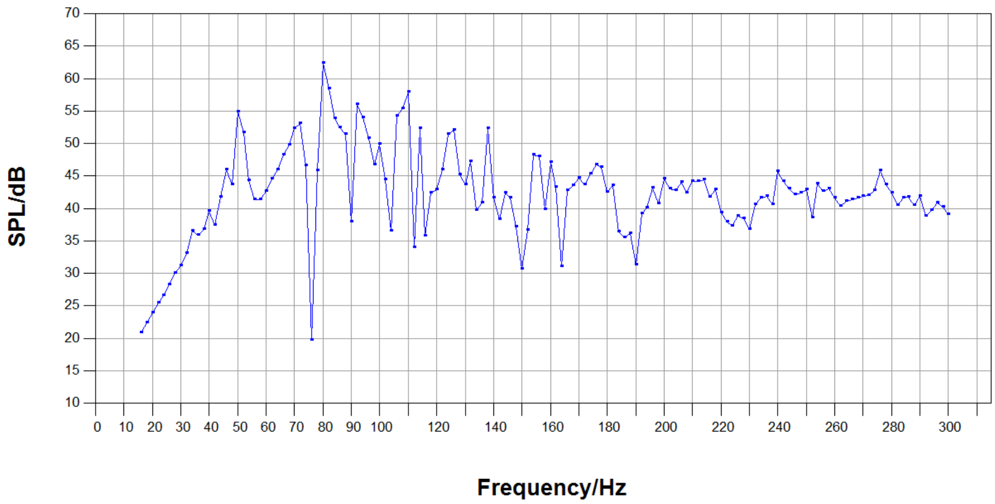


(b) SPL based on numerical method

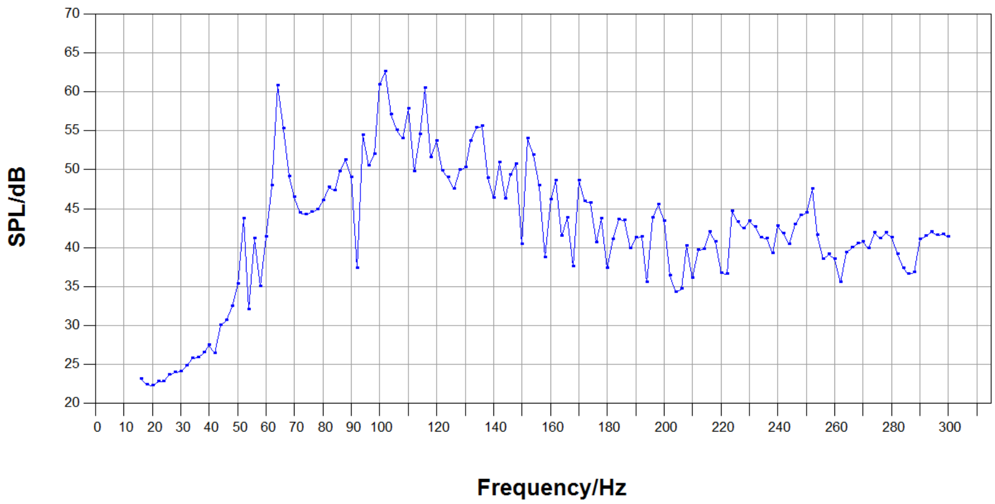
Figure 1 – verification results between theoretical method and numerical method

3. FEATURES ANALYSIS ON THE CYLINDRICAL SHELL RADIATION NOISE

In this section, the impacts and features on acoustic radiation noise are studied. The cylindrical shell with hemispherical shell is analyzed under different thickness, observing position, excitation point, medium, length, and radius. The cylindrical shell with different shell is also studied in the section. Firstly, the thickness is considered. The observing position is (0, 0, 100 m), the thickness are 0.015 m and 0.027 m respectively and the other basic parameters are the same in Sect. 2. The simulation result is shown in Figure 2. From Figure 2, the peak of SPL changes little with the thickness.



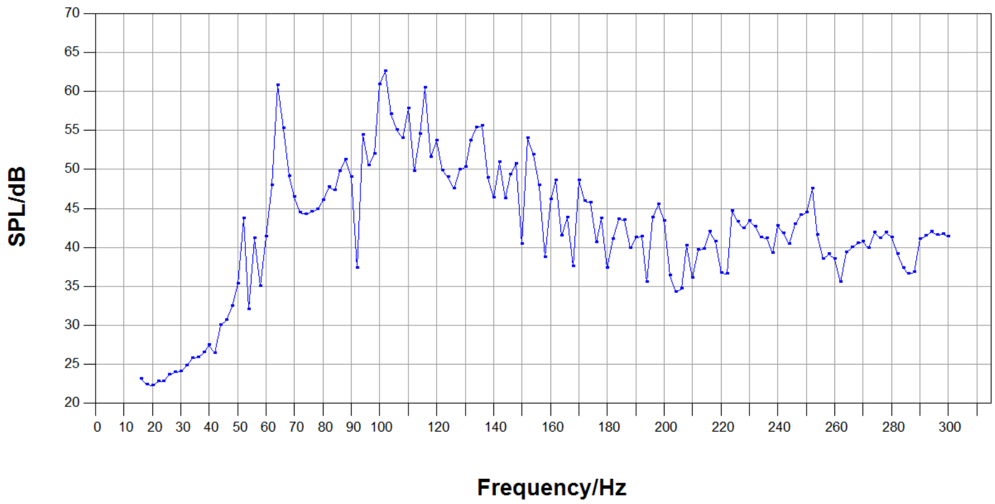
(a) SPL for thickness of 0.015 m



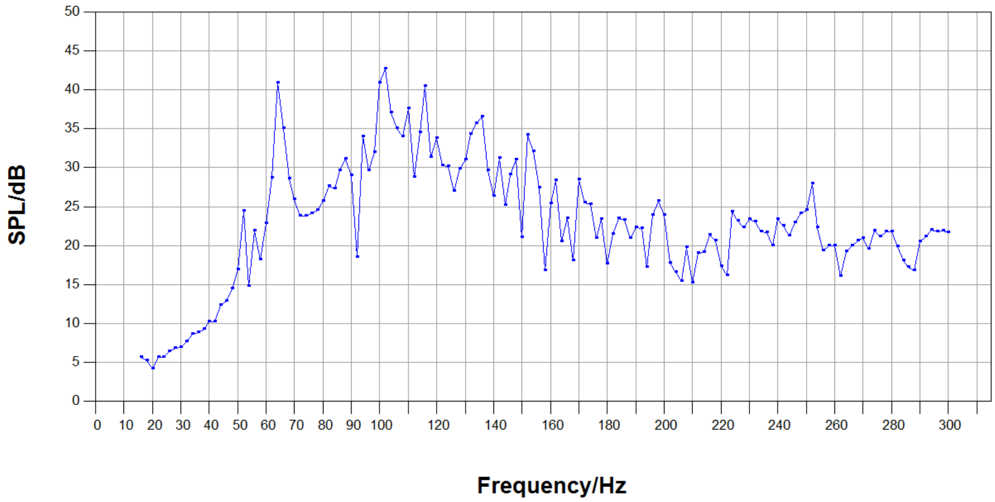
(a) SPL for thickness of 0.027 m

Figure 2 – SPL of different thickness

When the impact of observing position is analyzed, the other parameters are the same with Sec. 2. The variation of the SPL was observed by changing the observing position. The position is (0, 0, 100 m) and (0, 0, 1000 m) respectively. The simulation results are shown in Figure 3. It can be seen that the SPL with different observing position are same except the amplitude of the SPL.



(a) SPL for position (0, 0, 100 m)

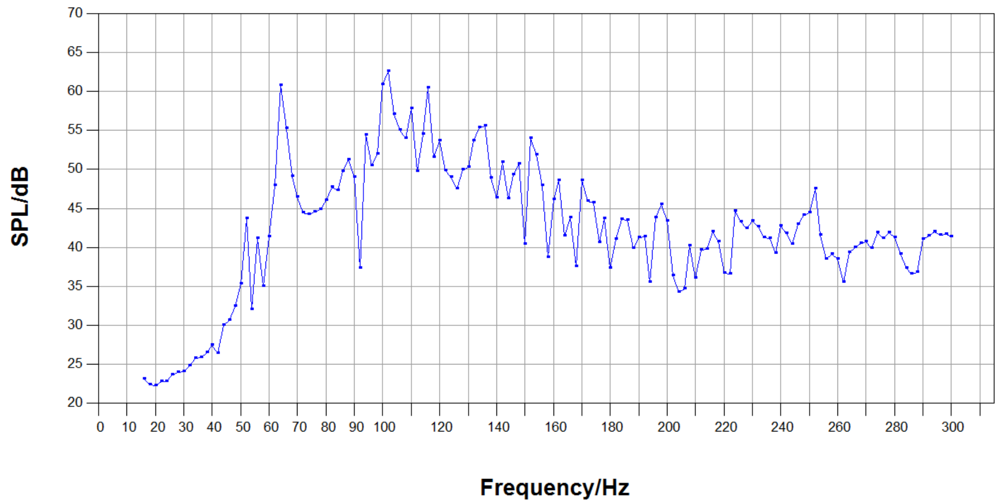


(b) SPL for position (0, 0, 1000 m)

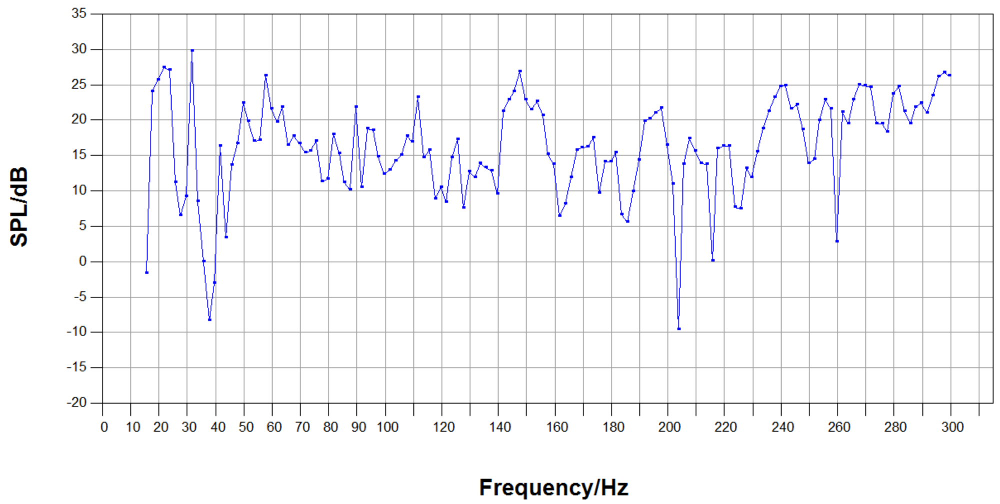
Figure 3 – SPL of different observing position

Then the different medium is analyzed. The operation conditions are underwater and semi-submersible respectively, the observing position is (0, 0, 100 m) and the other parameters are kept same with Sec. 2. Figure 4 shows the simulation results. From Figure 4, the peak of SPL changes with medium, and the change was very large. Therefore the medium has large impact on the SPL.

Then how the excitation position impacts the radiation noise is studied. The observing position is (0, 0, 100 m), and the other basic parameters are the same as in Sec. 2. The excitation point for position 1 is (0, 3.1 m, 0) and that for position 2 is (7.75 m, 0, 0). Through Figure 5, it can be seemed that the peak of SPL has little relationship with the position of the excitation point.

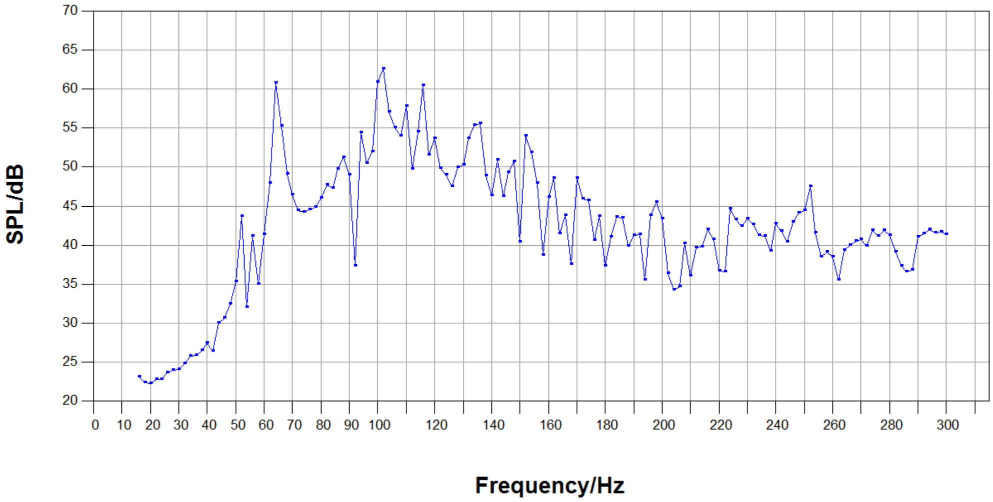


(a) SPL of underwater condition

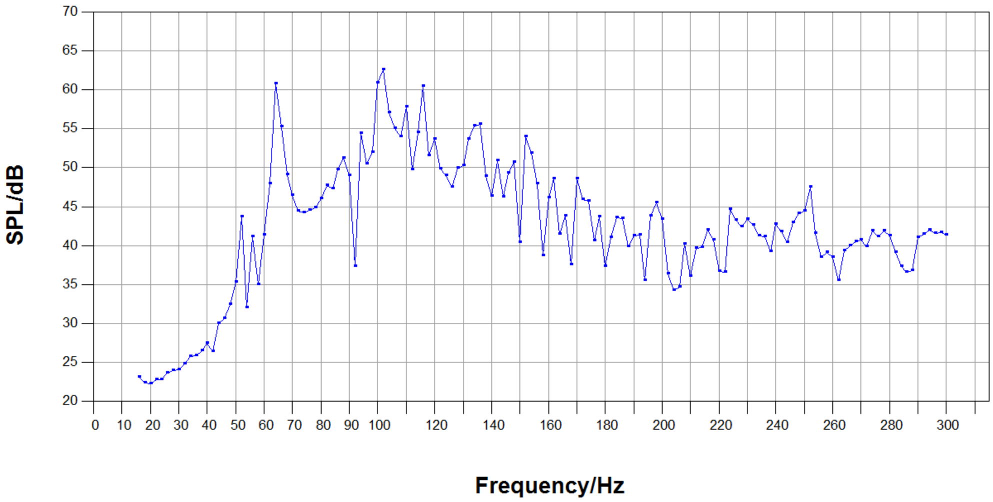


(a) SPL of semi-submersible condition

Figure 4 – SPL of different medium



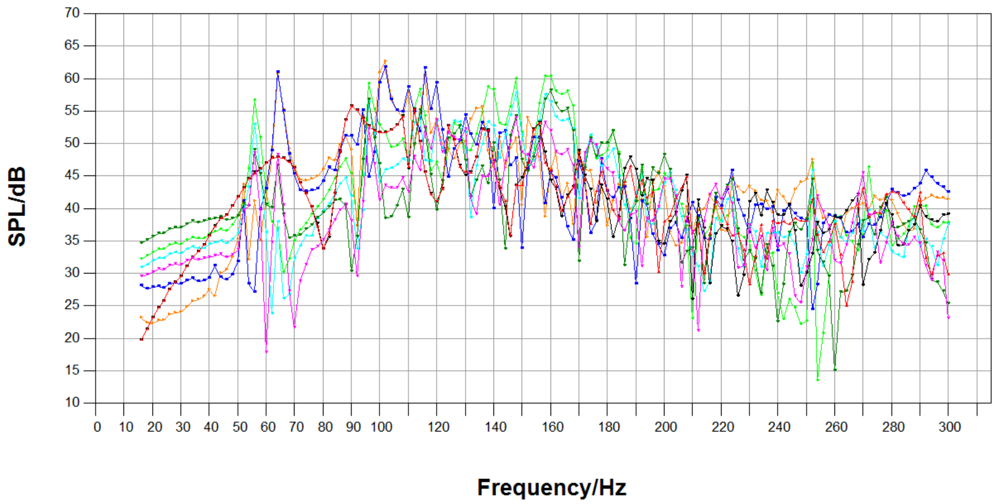
(a) SPL of excitation position 1



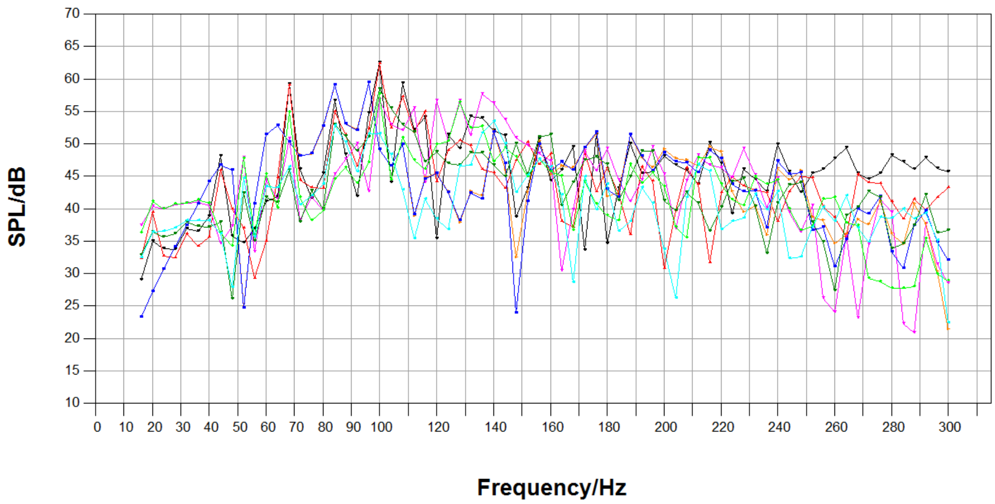
(a) SPL of excitation position 2

Figure 5 – SPL of different excitation position

When the impact of length on acoustic radiation is studied, the variation of the sound pressure radiation was observed by changding the size of the length. the observing positions are (100 m, 0, 0), (-100 m, 0, 0), (0, 0, 100 m), (0, 0, -100 m), (0, 100 m, 0), (70.1 m, -35.4 m, -43.3 m) , (-45.8 m, -51.4 m, -57.3 m), (-64.9 m, -47.3 m, 47.2 m), and (56.7 m, -41.5 m, 61.5 m) and the other parameters are kept same with Sec. 2. The simulation result is shown in Figure 6. The radius of shell is 3.1 m, the length is 9.3 m and 24.7 m, respectively. From Figure 6, the peak of the SPL changes with length, but the change is very small. So the change of length has little impact on the radiation noise.



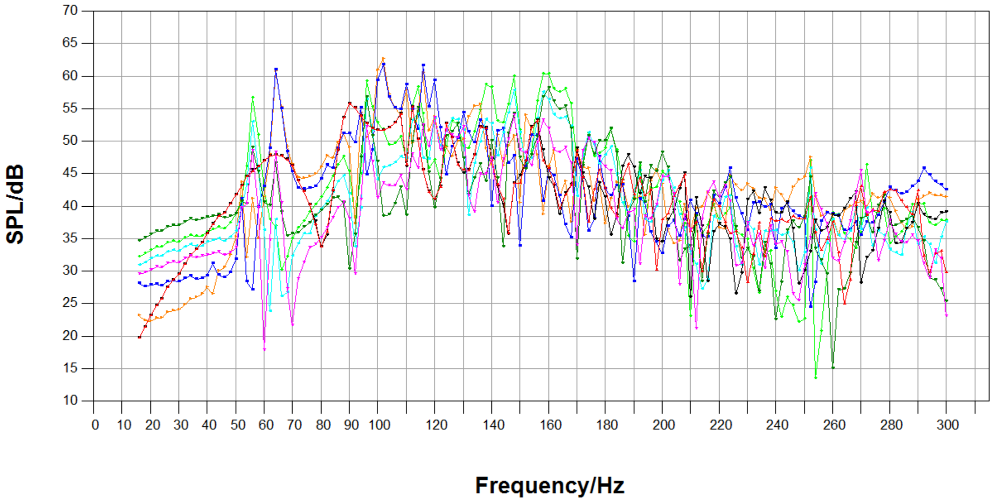
(a) SPL of length 9.3 m



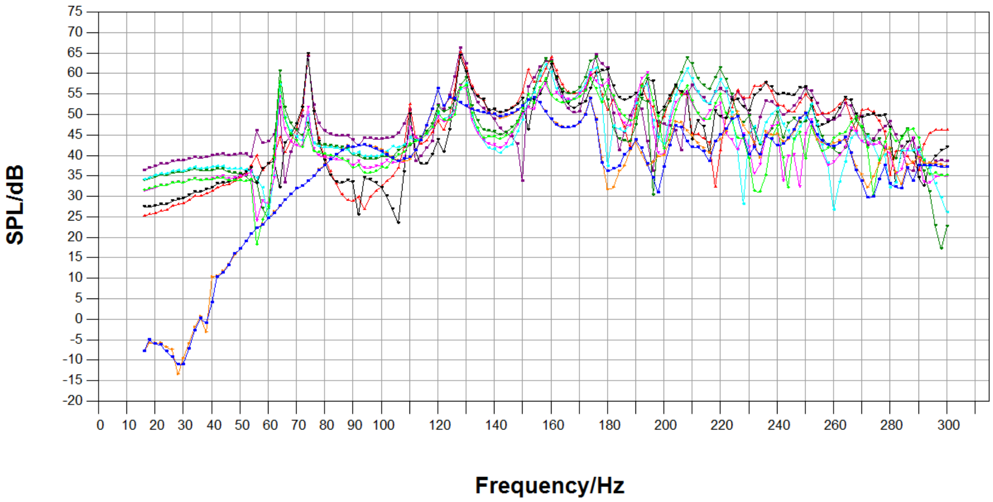
(a) SPL of length 24.7 m

Figure 6 – SPL of different length

When the impact of radius on acoustic radiation is analyzed, keep the other parameters same with Sec. 2. The observing positions are (100 m, 0, 0), (-100 m, 0, 0), (0, 0, 100 m), (0, 0, -100 m), (0, 100 m, 0), (70.1 m, -35.4 m, -43.3 m) , (-45.8 m, -51.4 m, -57.3 m), (-64.9 m, -47.3 m, 47.2 m), and (56.7 m, -41.5 m, 61.5 m). The change of the SPL is observed by different radius of 3.1 m and 2.3 m. The results are shown in Figure 7. It can be seen from Figure 7 that greater impact of pressure was generated by radius than other factors.



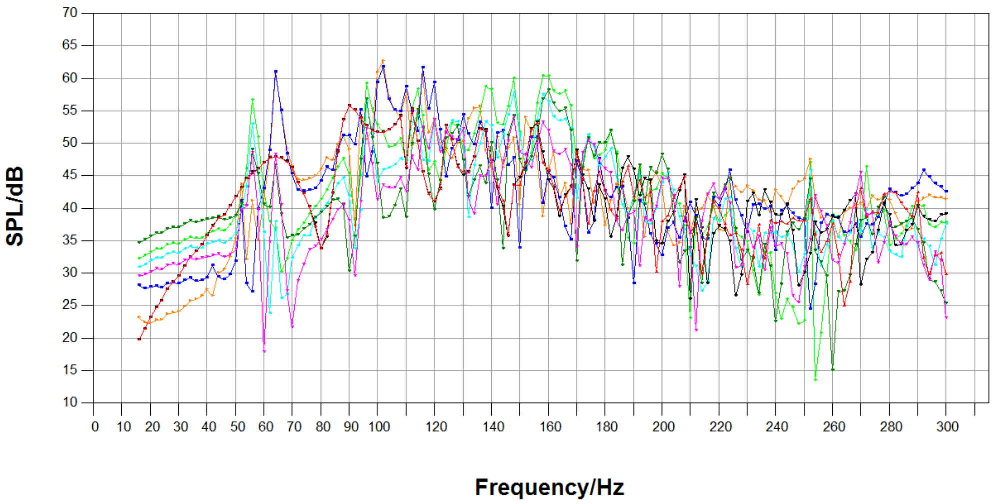
(a) SPL of radius 3.1 m



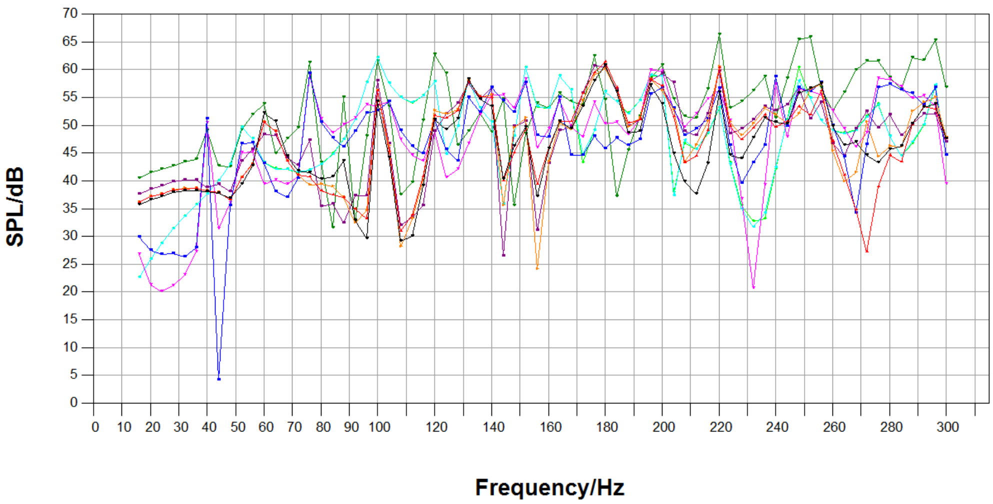
(b) SPL of radius 2.3 m

Figure 7 – SPL of different radius

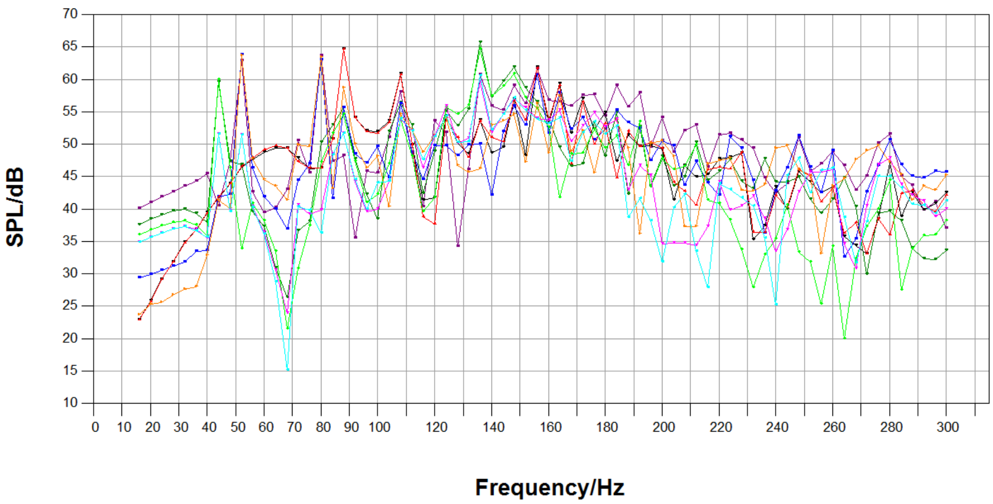
Then the cylindrical shell with different shell structure is studied, and the other parameters are as the same as in Sec. 2. The observing positions are (100 m, 0, 0), (-100 m, 0, 0), (0, 0, 100 m), (0, 0, -100 m), (0, 100 m, 0), (70.1 m, -35.4 m, -43.3 m) , (-45.8 m, -51.4 m, -57.3 m), (-64.9 m, -47.3 m, 47.2 m), and (56.7 m, -41.5 m, 61.5 m). The simulation results are shown in Figure 8. From Figure 8, the SPL has large relationship with different structure.



(a) SPL of hemispherical shell structure



(b) SPL of round pillars shell structure



(c) SPL of semi-elliposoid shell structure

Figure 8 – SPL of different shape

4. CONCLUSION

In this paper, the radiated noise spectra of cylindrical shell vibration have been predicted by FE/BEM method. Simulation results show that the peak of the radiated noise is associated with the dimension fo the underwater targets, structures and excitation points. Althrough these factors impacts the positon of peak of the SPL, the medium, radius and shell structure parameters were the main influential factors. The method presented in this paper is instructive in target identification.

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REFERENCES

1. Junger M C, Feit D. Sound, Structure, and Their Interaction. 2nd ed. Cambridge, The MIT Press; 1986.
2. Guo Y P.Acoustic Radiation From Cylindrical Shells Due to Internal Forcing, J Acoust Soc Am. 1996; 99:1495-1505.
3. Stepanishen P R, Chen H W. Nearfield Pressures and Surface Intensity for Cylindrical Vibrators. J Acoust Soc Am. 1984;76:942-948.
4. Junger M C.Dynamic Behavior of Reinforced Cylindrical Shells in a Vacuum and in a fluid. Appl Mech. 1954;21:35-41.
5. Junger M C. The Physical Interpretation of the Expression for an outgoing wave in Cylindrical Coordinates. J Acoust Soc Am. 1953;25:40-47.
6. Tang W L.Priciples of Underwater Noise. Shanghai Jiao Tong University Press; 1982.
7. Liu QingYu, Fang Shiliang, Cheng Qiang, et al.. Intrinsic Mode Characteristic Analysis and Extraction in Underwater Cylindrical Shell Acoustic Radiation. Science China. 2013; 56(7):1339-1345.
8. Everstine G C, Henderson F M.Coupled Finite Element/Boundary Element approach for fluid-structure interaction. J Acoust Soc Am. 1990; 87(5):1938-1947.
9. Sgard F, Atalla N, Nicolas J.Coupled FEM-BEM Approach for Mean Effects on Vibro-acoustic Behavior of Planar Structure. J Acoust Soc Am. 1994; 32(12):2351-2358.