Influence of Homogenization of Foundation Impedance on Underwater Acoustic Radiation of a Stiffened Cylindrical Hull

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ABSTRACT

Based on a stiffened cylindrical hull model, this paper examines influence of homogenization of foundation impedance on underwater vibration and radiated noise characteristic of a ship. A FEM model of a stiffened cylindrical hull with a foundation is established. By changing the size and shape parameters of foundation, the characteristic of the underwater radiated noise of a stiffened cylindrical hull and the characteristic of foundation impedance have been explored. On the basis of it, the influence homogenization of foundation impedance on the underwater radiated noise characteristic of the stiffened cylindrical hull is discussed in details. Research shows that compared with the influence of impedance on the underwater radiated noise of stiffened cylindrical hull, the homogenization of foundation impedance has less influence on it. But the more homogenous the foundation impedance is, the less sound pressure level the stiffened cylindrical hull has. To reduce the underwater radiated noise of ships, more homogenous the foundation impedance should be designed.

Keywords: stiffened cylindrical hull; foundation impedance; homogenization; underwater vibration and radiated noise.
I-INCE Classification of Subjects Number(s): 54.3

1. INTRODUCTION

Underwater radiated noise severely limits the realization of the goal of the quiet ship, it has been the focus of noise control on ship. As an important mediator of noise transfer from mechanical device to the ship's hull, the impedance of foundation determines the size of the proportion of the vibrational energy which is the input from the vibration source to the hull structural members, it is also an important acoustical design parameters (1-3). In recent years, domestic and foreign scholars have done a lot of research on the impedance characteristics and underwater radiated noise characteristics of the ship's foundation structure, such as literature (4) based on the impedance points system, it has explored the mechanical impedance characteristics of the suspension-type foundation, and analyzed the influence of the structural parameters of the foundation on its mechanical impedance, and conducted the optimal design on parameters of the cantilever-type base structure. Literature (5) has researched the effects of structural and material parameters on the foundation of the ship radiated noise, through the analysis of foundation structure vibration response and the vibration transmission characteristic. However, the research work is still relatively small, which are about the relationship between the foundation structure and mechanical impedance of the underwater radiated noise, and the influence of homogenization of foundation impedance on underwater radiated noise.

The article selected the stiffened cylindrical hull and typical foundation of ship as the research object, by changing the methods of reinforcement on the panel of foundation and the thickness of the strengthened structure, based on the stiffened cylindrical hull model, this paper examines influence of foundation impedance on underwater vibration and radiated noise characteristic of a ship. On the basis of it, the influence homogenization of foundation impedance on the underwater noise characteristic of the stiffened cylindrical hull is discussed in details.

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2. THEORETICAL BASIS

Mechanical impedance is defined as the ratio of the complex amplitude of the excitation force in the complex amplitude of the motion response, according to the style of the motion response, the expression of mechanical impedance often be divided into six: displacement impedance, velocity impedance, acceleration impedance, displacement admittance, velocity admittance and acceleration admittance, the six expressions of mechanical impedance are equivalent (6).

The general expression of mechanical impedance as follows:

$$Z_{ij}^{\mathrm{mn}} = \frac{F_i^m}{V_j^n} \tag{1}$$

Wherein: F_i^m is the force of the i-th degree of freedom at the point m; V_j^n is the vibration velocity of the j-th degree of freedom at the point n;

When i = j, it is the direct impedance; when i $\neq$ j, it is the cross impedance; when m = n, it is the ordinary impedance; when m $\neq$ n, it is the transfer impedance.

Under the excitation force, due to the radiated noise caused by the vibration of the foundation structure on the stiffened cylindrical hull is mainly perpendicular to the direction of the hull, so, this research based on the ordinary direct mechanical impedance, the unified expression of mechanical impedance of the foundation structure of stiffened cylindrical hull as follows:

$$Z = \frac{F}{V} \tag{2}$$

The vibration differential equation of the foundation structure can be described as follows:

$$\left[M\right]\left\{\ddot{\ } \quad \dot{\ } \quad t\right\} = \left\{F(\mathrm{t})\right\} \tag{3}$$

It is assume that the excitation force of the system is:

$$F(\mathrm{t}) = F_0 e^{j\omega t} \tag{4}$$

So the steady-state response of the corresponding system can be expressed as:

$$X = X_0 e^{j\omega t} = X_0 \sin(\omega t + \varphi) \tag{5}$$

Then the velocity impedance of the system is :

$$Z = \frac{F}{V} = \frac{F_0}{X_0 \cdot \omega} e^{j\Delta\varphi} \tag{6}$$

Wherein: X_0 is the max deformation displacement of vibration.

3. RESEARCH ON THE CHARACTERISTIC OF FOUNDATION IMPEDANCE AND UNDERWATER RADIATED NOISE OF STIFFENED CYLINDRICAL HULL

3.1 The Vibration and Noise Prediction Model of Ship Cabin and Foundation

Selected a typical ship cabin as the background, the finite element model is established. During the modeling, the model is a reasonable simplification according to the computational requirements, the finite element model mainly selected SHELL units, such as the outer panel of the cabin structure, bulkheads, decks and foundation structure and so on. In addition, using a variety of T profiles as ribs in the outer plate cabin structure, bulkheads, decks and other structures, to close to the stiffness of the entire ship hull. The research focuses on the foundation structure of cabin, the base structure has been done some detailed treatments during the modeling. The model of ship cabin is 5m in length, and the diameter is 3m, each about 0.5m away from the lowest point of the cabin to establish the foundation. The foundation panel is 0.9m in length and 0.6m in width, the height of web is 0.4m, and the entire cabin model totally includes 6383 finite elements. The involved parameters of the model structure and material are shown in Table 1, the model of cabin and foundation structure shown in Figure 1 and Figure 2.

Table 1 –The main structure of model and the parameters of material

parameters	value
Thickness of shell plate t_1/mm	30
Thickness of transverse bulkhead t_2/mm	14
Thickness of the foundation panel t_3/mm	18
Thickness of the foundation web and brackets t_4/mm	20
Density of the material $\rho / kg \cdot m^{-3}$	7800
Elastic modulus $E / N \cdot m^{-2}$	2.1×10^{11}
Poisson's ratio ν	0.3

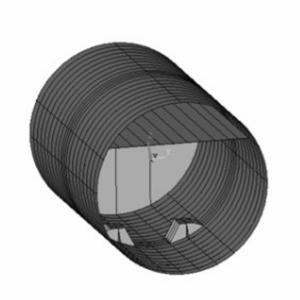


Figure 1– Model of cabin and foundation structure

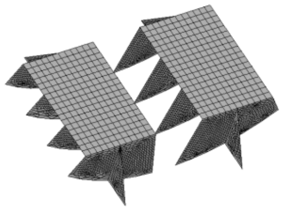
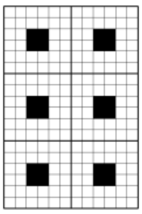


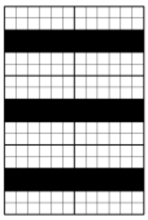
Figure 2 – FEM of foundation structure

3.2 Research on Characteristic of Underwater Radiated Noise of Stiffened Cylindrical Hull

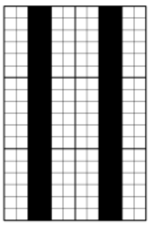
The research based on the model of cabin and foundation structure, according to the form of the foundation structure, the foundation panel were divided into six parts, each part used the same reinforcing methods. Four different manners have been used to strengthen the structure of the foundation panel, including: Central reinforcement, transversal reinforcement, longitudinal reinforcement and "cross" reinforcement, the reinforcing methods of foundation panel are shown in Figure 3.



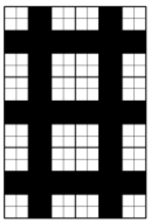
(a).Central reinforcement



(b).Transversal reinforcement



(c).Longitudinal reinforcement



(d)."cross" reinforcement

Figure 3 – Schematic diagram of the reinforcing methods of foundation panel

Six nodes are selected as the excitation point and applied to the reinforced region of foundation panel, taking the center of cabin as the center of sphere and the radius R equals 5 meters, the flow field is established. On the test surface of sound pressure, the test points are arranged evenly, which is used to record the underwater radiated noise of stiffened cylindrical hull. It can be obtained after calculation when the thickness of foundation panel is 18mm (design condition), the variation curve of the underwater radiated noise of the stiffened cylindrical hull is shown in Figure 4.

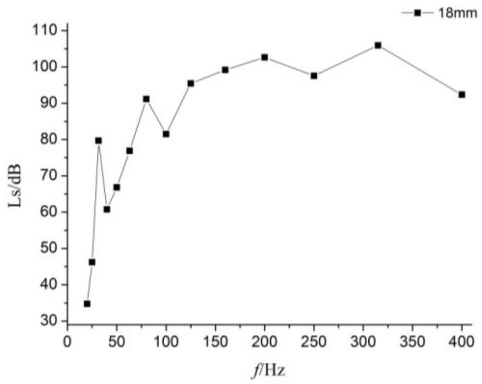
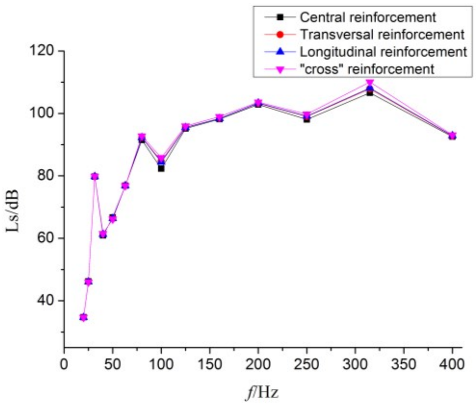


Figure 4 – The variation curve of the underwater radiated noise under design condition

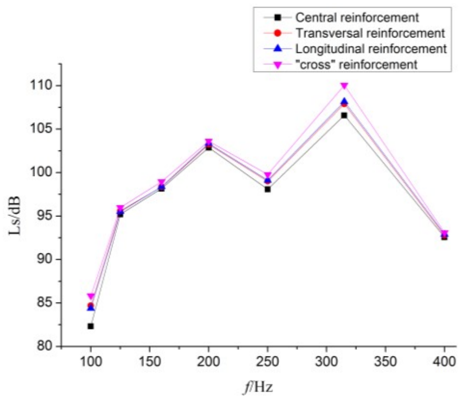
As shown in Figure 4, the underwater radiated noise of stiffened cylindrical hull changes with the increase of the frequency in the entire low frequency section, the change trend of the stability after first fluctuation increases. In the 20-200Hz frequency band, the radiated noise of the stiffened cylindrical hull has obvious fluctuation with the change of frequency, and the peak value occurs at the 40Hz and 80Hz frequency points; When the frequency reaches 200Hz, the radiated noise reaches the maximum and keeps stable state with the increase of frequency.

3.2.1 Influence of Reinforcing Method on Radiated Noise of Stiffened Cylindrical Hull

To illustrate the influence of reinforcing method on radiated noise of stiffened cylindrical hull, now taking an example of the thickness of reinforcing region is 6mm, the curve relationship between the two is shown in Figure 5.



(a).20Hz-400Hz



(b).100Hz-400Hz

Figure 5 – The effect of reinforcing method on the underwater radiated noise

As shown in Figure 5, in the 20Hz-100Hz frequency band, the variation curves of the radiated noise of the stiffened cylindrical hull under various reinforcing methods are basically consistent with the frequency, it shows that the reinforcing method has less influence on the underwater radiated noise of stiffened cylindrical hull in this frequency band; In the 100Hz-400Hz frequency band, the difference between the two is obvious, and "cross" reinforcement method has the biggest influence on underwater radiated noise of stiffened cylindrical hull, central reinforcement method has the least influence on it, and the transversal reinforcement method and longitudinal reinforcement method have the similar effect on it.

3.2.2 Influence of Thickness of Foundation Panel on Radiated Noise of Stiffened Cylindrical Hull

On the basis of the above analysis, the influence of thickness of foundation panel on radiated noise of stiffened cylindrical hull is discussed. This section respectively calculated the underwater radiated noise under 7 various conditions, which are different thickness of reinforcing region on foundation, including: 6mm, 10mm, 14mm, 18mm (design condition), 22mm, 24mm and 28mm. Taking an example of “cross” reinforcement method, the relationship between the underwater radiated noise of stiffened cylindrical hull and the thickness of the reinforcing regional structure is shown in Figure 6.

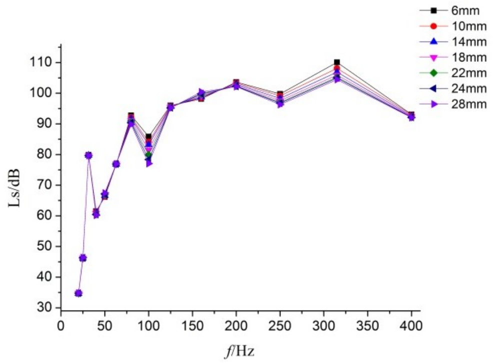
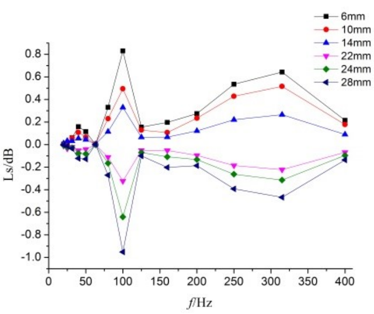


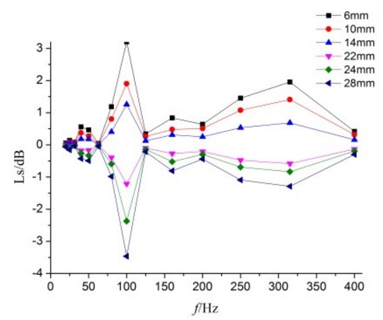
Figure 6 – the relationship between underwater radiated noise and thickness of plate

As shown in Figure 4 and Figure 6, the variation of the underwater radiated noise of the stiffened cylindrical hull under different conditions is consistent with the change of the frequency. In the 20Hz-100Hz frequency band, the difference among the curves is very small. When the frequency reaches 100Hz, the curves appear obvious difference, especially in the 100Hz frequency point and 200Hz-400Hz frequency band.

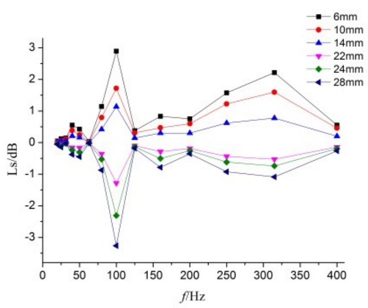
In order to further illustrate the relationship between the underwater radiated noise of stiffened cylindrical hull and the thickness of the reinforcing regional structure, now taking the underwater radiated noise of stiffened cylindrical hull under design condition for basis, the relative variation of underwater radiated noise under other working conditions are shown in Figure 7.



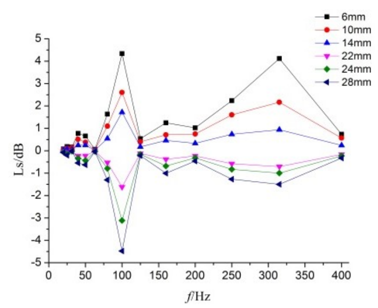
(a).Central reinforcement



(b).Transversal reinforcement



(c).Longitudinal reinforcement



(d).“cross” reinforcement

Figure 7 – the relative variation of underwater radiated noise under other conditions

As shown in Figure 7, under the different reinforcing methods, the relative variation of the radiated noise of the stiffened cylindrical hull is basically the same with the change of the thickness of the structure, but there is a significant difference between the relative changes. For any kind of reinforcing method, with the increase of the thickness of the structure, the underwater radiated noise of stiffened cylindrical hull is decreasing. By contrasting the range of the vertical coordinate in the curve, it can be found that the relative variation of the radiated noise of the stiffened cylindrical hull under the "cross" reinforcement method is larger with the change of the thickness of structure.

Based on the above research, by changing the methods of reinforcement on the panel of foundation and the thickness of the strengthened structure, the relationship between the frequency and underwater radiated noise under different thickness and reinforcing methods are compared and analyzed. The variation curve between thickness of reinforcing region and the total level of the underwater radiated noise of the stiffened cylindrical hull under different reinforcing methods is shown in Figure 8.

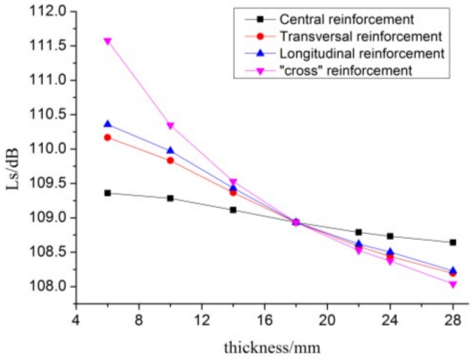


Figure 8 – The variation curve between thickness and total level of underwater radiated noise

As the comparison results shown in Figure 8: with the increase of thickness of strengthen regional structure, the underwater radiated noise of stiffened cylindrical hull decreases under the same reinforcing method, and When the thickness is less than 18mm, the variation of underwater radiated noise is more obvious, and the change is relatively small after the thickness is larger than 18mm; At the same thickness of reinforcing regional structure on foundation panel, when the thickness of plate is 18mm, the underwater radiated noise of stiffened cylindrical hull under the 4 reinforcing methods are the same. When the thickness is less than 18mm, the underwater radiated noise of stiffened cylindrical hull has the maximum value under the "cross" reinforcement method, but when the thickness is greater than 18mm, the maximum value of radiated noise occurs in the central reinforcement method. In the whole range of plate thickness variation (the thickness of the plate is changed from 6mm to 28mm), during the four reinforcing methods, the influence of "cross" reinforcement method on underwater radiated noise of stiffened cylindrical hull is the biggest, which is about 3.54dB. The transversal reinforcement method and longitudinal reinforcement method have the similar effect on it, which is about 2.05dB. And Central reinforcement method has the least influence on it, which is about 0.72dB.

3.3 Research on The Characteristic of Foundation Impedance

The FE/SEA analysis module in VA-ONE software is used to calculate the mechanical impedance of the foundation structure, based on the FEM model mentioned above, the mechanical impedance of the foundation structure in the whole frequency range (20Hz~400Hz) can be obtained by the calculation formula of the mechanical impedance in the first section. The variation curve of mechanical impedance of foundation structure with frequency under design condition is shown in Figure 9.

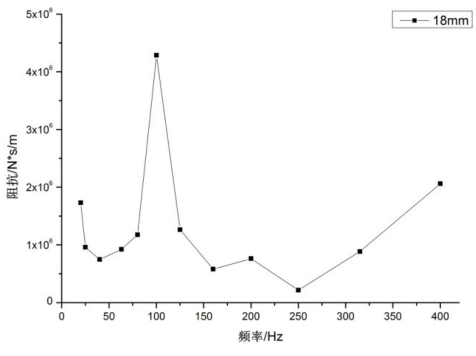


Figure 9 –The variation curve of mechanical impedance with frequency under design condition

The As shown in Figure 9, the variation of mechanical impedance of the foundation structure with the frequency changes significantly, and the peak value occurs at the 100Hz frequency point.

In accordance with the analysis of the upper section on the characteristics of underwater radiated noise of stiffened cylindrical hull, the same analysis method is adopted in this section. By changing the methods of reinforcement on the panel of foundation and the thickness of the reinforced structure, the characteristic of mechanical impedance of the foundation structure is analyzed. By processing the data obtained from the numerical calculation, the variation curve of the mechanical impedance of the foundation structure with the reinforcing method can be obtained in the entire low frequency section, as shown in Figure 10.

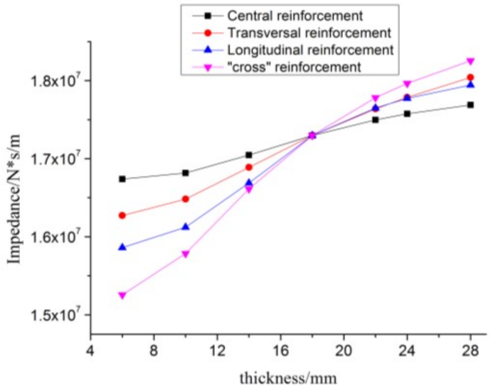


Figure 10 – The variation curve of the mechanical impedance with thickness of plate

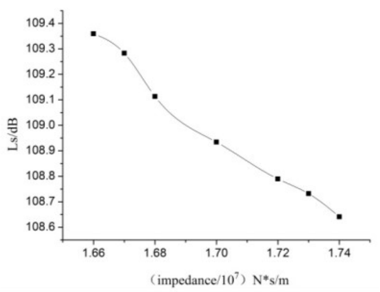
As shown in Figure 10, under the same thickness of plate, the "cross" reinforcement method has the biggest influence on mechanical impedance of foundation structure, the central reinforcement method has the least influence on it, and the transversal reinforcement method and longitudinal reinforcement method have the similar effect on it. Under the same reinforced method of foundation panel, the mechanical impedance of the foundation structure increases with the increase of plate thickness. When the increment of plate thickness is same, the “cross” reinforcement method has the biggest influence on increment of impedance, and the central reinforcement method has the least influence on it.

In general, through the analysis of characteristics of mechanical impedance of foundation structure and underwater radiated noise of stiffened cylindrical hull under the different thicknesses of foundation panel and the reinforcing methods, it can be obtained that there is a certain relation between the mechanical impedance of the foundation structure and underwater radiated noise of stiffened cylindrical hull. And during the four reinforcing methods, the influence of "cross" reinforcement method on the two factors is the biggest. Central reinforcement method has the least influence on it. And the transversal reinforcement method and longitudinal reinforcement method have the similar effect on it.

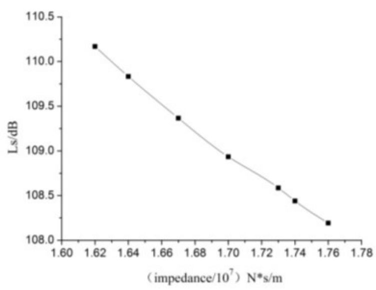
3.4 Influence of Homogenization of Foundation Impedance on Underwater Acoustic Radiation of Stiffened Cylindrical Hull

3.4.1 Research on The Relationship Between Foundation Impedance and Underwater Radiated Noise

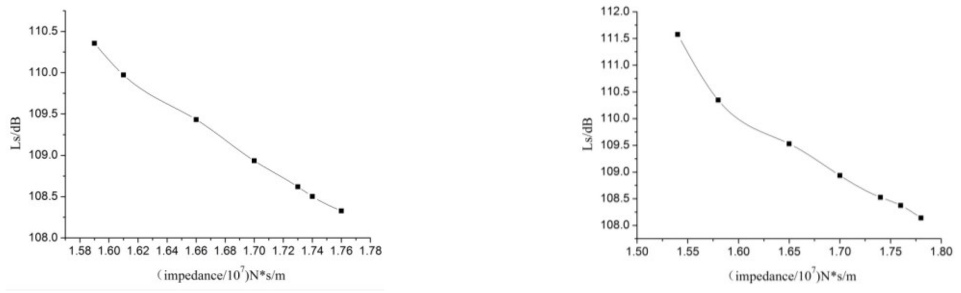
Based on the analysis of the underwater radiated noise characteristics and the mechanical impedance characteristics of the foundation structure, the relationship between the foundation impedance and the underwater radiated noise of stiffened cylindrical hull is discussed. Figure 11 shows that the relationship between the mechanical impedance of the foundation and the radiated noise of stiffened cylindrical hull under different reinforcing methods.



(a).Central reinforcement



(b).Transversal reinforcement



(c).Longitudinal reinforcement (d).“cross” reinforcement

Figure 11 – the relationship between mechanical impedance and underwater radiated noise

As shown in Figure 11, for any kind of reinforcing method, the underwater radiated noise of stiffened cylindrical hull is reducing with the increase of mechanical impedance. Through comparing the variation of mechanical impedance and underwater radiated noise of stiffened cylindrical hull, when the increment of mechanical impedance of foundation structure is large, the reduction of underwater radiated noise also increases accordingly.

3.4.2 Influence of Homogenization of Foundation Impedance on Underwater Acoustic Radiation

On the basis of the above analysis, the influence of homogenization of the foundation impedance on the acoustic radiation of stiffened cylindrical hull is discussed. According to the above analysis, to ensure the homogenization of foundation impedance as a single variable, the Influence of mechanical impedance of foundation structure on underwater radiated noise of stiffened cylindrical hull should be avoided.

Through the above calculation, it can be found that the mechanical impedance of foundation structure of four conditions are equal. The four conditions are including: the structure of plate thickness is 28mm in the central reinforcement method, the structure of plate thickness is 24mm in the transversal reinforcement method and longitudinal reinforcement method, the structure of plate thickness is 22mm in the “cross” reinforcement method.

The uniformity of the foundation impedance is represented by the standard deviation of each part of the impedance of the foundation panel, and the smaller the standard deviation is, the higher the uniformity of impedance is. Through the comparison of the uniformity (standard deviation) of the mechanical impedance under the four kinds of structure form, the influence of homogenization of foundation impedance on underwater acoustic radiation is discussed as shown in the Table 2.

Table 2– The uniformity of impedance and sound source level of each condition

Condition name	standard deviation	sound source level /dB
Central reinforcement（28mm）	566463	108.64
Transversal reinforcement（24mm）	555191	108.53
Longitudinal reinforcement（24mm）	554912	108.50
“cross” reinforcement（22mm）	553464	108.44

As shown in Table 2, the radiated noise of the stiffened cylindrical hull is decreased with the decrease of the standard deviation, that is, when the mechanical impedance of the foundation structure is constant, the more uniformity of the foundation impedance is, the smaller the radiated noise is. But compared to the mechanical impedance, the effect of the uniformity of impedance on the radiated noise of the stiffened cylindrical hull is smaller.

4. CONCLUSIONS

Based on the FEM, the characteristic of the underwater radiated noise of a stiffened cylindrical hull and the characteristic of foundation impedance have been explored. By changing the size and shape parameters of foundation, the influence homogenization of foundation impedance on the underwater radiated noise characteristic of the stiffened cylindrical hull is discussed in details. The following conclusions can be obtained from the above research:

1. During the four reinforcing methods, "cross" reinforcement method has the biggest influence on underwater radiated noise of stiffened cylindrical hull, the central reinforcement method has the least influence on it, and the transversal reinforcement method and longitudinal reinforcement method have

the similar effect on it.

2. The mechanical impedance of foundation structure increases with the increase of plate thickness. And the increment of impedance of foundation also increases, when the increment of plate thickness increase. Especially in the 100Hz frequency point and 200Hz-400Hz frequency band, the increment of impedance appears obvious difference.
3. There is a certain relation between the mechanical impedance of the foundation structure and underwater radiated noise of stiffened cylindrical hull, that is, the underwater radiated noise of stiffened cylindrical hull is reducing with the increase of mechanical impedance.
4. When the mechanical impedance of foundation structure is constant, the more homogenous the foundation impedance is, the less sound pressure level the stiffened cylindrical hull has. But compared with the influence of impedance on the underwater radiated noise of stiffened cylindrical hull, the homogenization of foundation impedance has less influence on it.

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