Noise Prediction and Control in a Cruise Ship

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Abstract：Based on the statistical energy analysis (SEA) method, the noise prediction of the cruise ship's cabins was analyzed and the results show that the noise energy of the engine room (ER) is the highest in the whole cabins, and the energy propagates in the direction of the ship's bow and stern with the ER centered. In order to reduce the noise of the ER, the main characteristics of the noise source were analyzed. The contribution rate of each noise source to the ER and the input power of the diesel engine structure-borne and air-borne noise to the ER were analyzed and calculated. The analysis shows that air-borne noise of diesel engine is the main noise source in the ER. Then the acoustic enclosures were applied to the diesel engine to control air-borne noise and the sound insulation effect of the acoustic enclosure under different working conditions was studied. The results shows that in the case of only considering the air-borne noise of the diesel engine, the sound pressure level(SPL) of the ER is reduced by about 36dB(A)~62dB(A). In the case where all excitations are loaded, the SPL of the cabin is reduced by an average of about 10.8dB (A), which shows a better sound insulation effect.

1. Introduction

The cruise ship is a typical high-tech, high value-added vessel[1], which requires a high level of comfort. The comfort of the cruise ship is mainly reflected in vibration and noise of the cabins. The main power equipment of the cruise ship are located in the ER. The research on noise reduction in cruise ship cabins is of great significance and of great practical value for future domestic development in this field.

At present, the noise prediction methods for ship cabins mainly include finite element method, boundary element method and SEA[2]. In recent years, many scholars have used SEA to perform noise prediction analysis on relevant ship cabins. Wen Huabing et al.[3] conducted noise prediction analysis on the cabins of the tug, and determined the size and location of the excitation source, and compared the forecast results with experimental results, and calculated the contribution rate of the excitation source to the target cabin. The results show that the feasibility of the SEA method in forecasting cabin noise was verified. Wang Chong[4] forecasted and analyzed the cabin noise of a luxury yacht on the sea, and obtained specific treatment measures for the noise exceeding the standard cabin based on the energy transfer path. Li Zhuoliang[5] analyze the transmission path of the structure-borne noise and air-borne noise, the result shows that the air-borne noise have great effect on the ER but the structure-borne noise spreads further than the air-borne noise.

This paper considers a large cruise ship as a research object by conducting noise prediction analysis of the ER. Then the characteristics of each noise source in the ER were analyzed, and the main noise source was identified as air noise of the diesel engine. The acoustic enclosures were applied to the

diesel engine to reduce the noise of the ER. Finally, the sound insulation effect of acoustic enclosure under different excitation conditions was studied.

2. Noise prediction of the ER

The cruise ship's finite element model was established based on the drawings of cruise ship and then the finite element model was converted into the SEA model according to the SEA subsystem partition principle. The total ship SEA model has 1365227 nodes, 8281 board subsystems and 492 sound cavities. And then the material properties of the plates were attached to the corresponding SEA subsystem, the plates below the waterline were added the attached water to simulate the coupling of seawater on the structural vibration, and the whole ship is automatically connected. Finally the loads were added to relevant position in the SEA model, and structural vibration acceleration levels were loaded on the pedestal by force. The air noise was loaded on the sound cavity through a diffuse sound field or sound power, and the model was calculated based on the SEA method. The result of noise prediction of the cruise ship in the frequency range of 63Hz to 8000Hz can be obtained, as shown in Figure. 1. The color from the bottom to the top represents the SPL in the right side. According to the picture, the maximum value of noise is located at the ER and the energy propagates in the direction of the ship's bow and stern with the ER centered. When the distance from the source cabin increases, the noise energy of the receiving cabin gradually decreases.
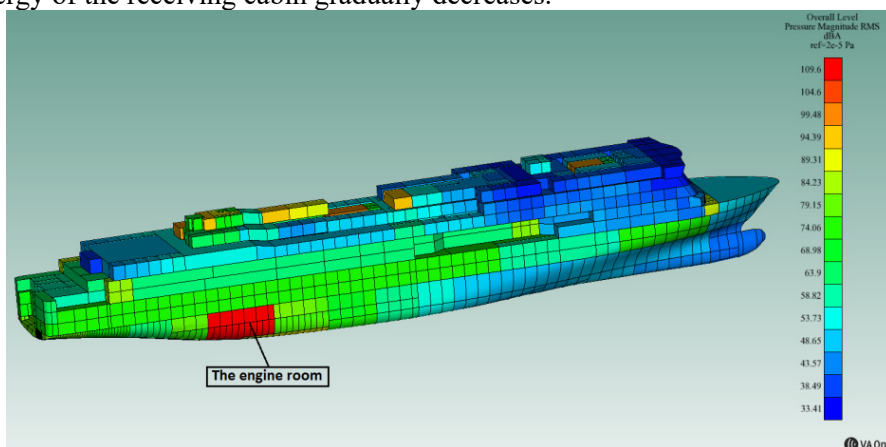

Figure.1 The noise prediction of the ER of cruise ship

The SPL of the ER at various frequencies is shown in Figure. 2. Because the front and rear ER are symmetrical to each other, the SPL of the two ERs is consistent, so the noise source of the front ER was selected for analysis in the following research. From the graph, the noise value of the cabin first increases and then decreases with an increase in frequency, and peaks appear around 800Hz, which is related to the spectral characteristics of the noise source. According to the results, the effective SPL of the ER is 109.6dB (A), and the limit value of the IMO standard is 110dB (A), with emphasis on the results, some measures for controlling the vibration and noise should be applied to reduce the noise value of the ER.
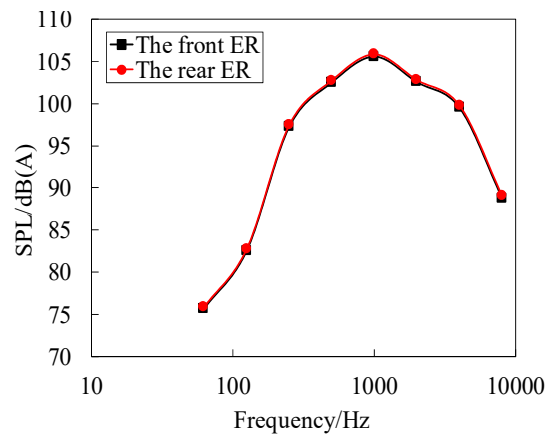
Figure.2 SPL of the ER

3. Analysis of noise source characteristics

The main power equipment of the ER are diesel engine, diesel generator set, shaft generator set and so on. According to the arrangement of cabins of the cruise ship, the propeller excitation also has a great influence on the noise source of the ER, so it needs to be considered and analyzed. In order to analyze the noise source characteristics, it is necessary to carefully analyze the contribution rate of the related excitation produced by the power equipment.

3.1 Analysis of the contribution rate of main noise source

The sound energy of the noise can be superimposed but the SPL not being superimposed. According to the superposition principle of the sound energy, the contribution rate of the single noise source to the total noise source is [6]:

$$\eta_n = \frac{E_n}{\sum_{i=1}^{N} E_i} = \frac{10^{L_{pn}/5}}{\sum_{i=1}^{n} 10^{L_{pi}/5}} \times 100\% \tag{1}$$

Where η_n is the contribution rate of the noise source n to cabin noise, E_n is the sound energy produced in the cabin by the noise source n, L_{pn} is the SPL produced in the cabin by the noise source n.

The main excitation sources of the cabin are the structural vibration and radiation noise of the diesel engine, diesel generator set and shaft generator set, and the propeller excitation. The SPL of the ER under different excitation were obtained by applying the relevant excitation of each power equipment separately, and then the contribution rate for different excitation sources to the noise source of the ER was calculated in Eq. (1). The calculation results are shown in Table. 1. The main noise of the ER is produced by the diesel engine. And the contribution rate of the diesel engine air noise to the ER is up to 95.55%. The diesel engine therefore needs to be carefully analyzed and its noise reduction measures be presented for analysis.

Table.1 The contribution rate of the noise source in the front ER

The ER	SPL/dB(A)	Contribution rate
Structure-borne noise of diesel engine	87.20	0.37%
Air-borne noise of diesel engine	111.67	95.55%
Exhaust noise of diesel engine	88.15	1.3%
Structure-borne noise of diesel generator set	80.62	0.14%
Radiation noise of diesel generator set	90.10	1.5%
Structure-borne noise of shaft generator set	75.48	0.13%
Air-borne noise of shaft generator set	85.29	1.0%
Propeller excitation	55.61	0.01%

3.2 Analysis of input power of structural vibration and radiation noise of diesel engine to ER
According to the analysis of the contribution rate of the main noise source of the ER, the diesel engine is the main noise source. The noise produced by the diesel engine can be divided into two parts: first, the vibration of the diesel engine is transmitted to the hull of the ship and the noise caused by the vibration of the structure, and the second is the radiation noise from the diesel engine. In order to analyze and reduce the noise level of the ER accurately, the contribution of structural vibration and air noise of diesel engine to ER needs to be analyzed. There are two sets of diesel engines in each cabin according to the layout of the ER, the input power of the two sets of diesel engines was analyzed, as shown in Figure. 3. The input power of the ER is significantly higher than the vibration by the air noise of the engine, and the air noise is the main input of the noise energy of the ER. To control the noise of the ER, the air noise of the diesel engine must be reduced.
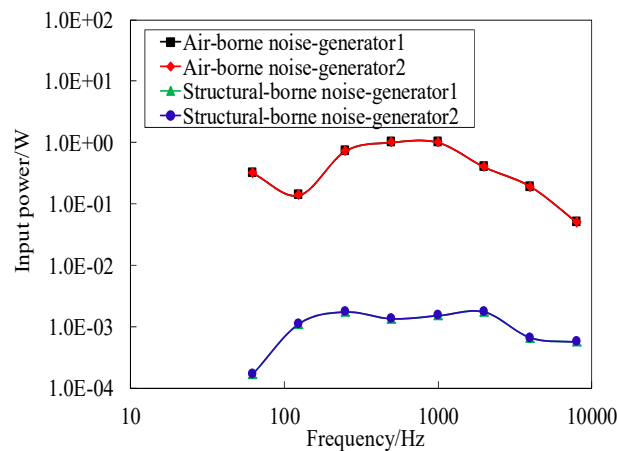

Figure.3 Input power of the ER

4. Noise control of the ER

The contribution rate of the main noise source and the input power of the structural vibration and air noise of the diesel engine to the ER can be obtained. The air noise of the diesel engine is the main noise source of the ER. For the control of air noise, the traditional measures are to lay damping materials and sound absorbing materials on the wall of the cabin, but the laying of relevant materials in the cabin has little effect on the source noise, because the sound absorbing material and damping material are mainly used to reduce the reverberation, and the attenuation of the direct sound is small. To control the noise level of diesel engine in the ER, we can reduce the radiation from the air noise of the diesel engine to the ER by using the acoustic enclosure in the ER. The structure is mainly composed of a certain stiffness and mass of metal, including all kinds of vibration isolating parts, elastic support unit and cooling system[5]. In this paper, the elastic element and cooling system of the acoustic enclosures are not considered, and the metal frame and sound insulation parts are built into the plate system. And the acoustic enclosure is square structure, its structural parameters are 2mm, 1mm plate thickness of inner and outer plate respectively, air layer of 30mm in the middle interior layer, and the inner wall is not set with a damping material. According to the design requirements of the acoustic enclosures and its standard, the wall of the acoustic enclosure should have a certain space to the noise source, which usually is the 1/3 of the space of the acoustic enclosure. In order to avoid the appearance of the resonance, the distance between the diesel engine and the wall of the acoustic enclosure should not be less than 100mm, so the size of the acoustic enclosure should be 10437×2347 ×4299mm according to the size of the diesel engine. The arrangement of the acoustic enclosures in the ER is shown in Figure. 4.
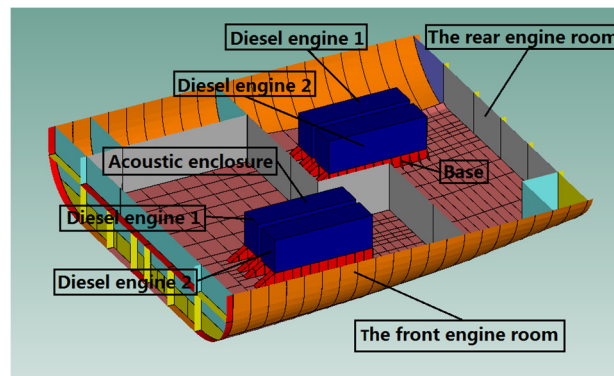
Figure. 4. Layout of the acoustic enclosure in the ER

To analyze the influence of the acoustic enclosure on the air noise of the main engine, the SPL of the ER with no acoustic enclosure is analyzed under the condition that the diesel engine air noise is applied separately, as shown in Fig. 5(a). The acoustic enclosure can effectively reduce the noise level and the influence of the diesel engine's air noise on the ER. At the same time, with an increase in frequency, the sound insulation effect is gradually improved. The minimum noise reduction effect is about 36 dB (A), and the maximum noise reduction effect is about 62 dB (A). Generally speaking, considering the excitation of diesel engine's air noise, the acoustic enclosure has a good noise reduction effect and is also mainly concentrated in the medium and high frequency range.

The above analysis only takes into account the air noise of the diesel engine, in order to accurately analyze the noise reduction effect of the acoustic enclosures to the ER. In the case of all excitation of the diesel engine and diesel generator set, the SPL of the ER is compared and analyzed under different acoustic enclosure. The simulation results are as shown in Figure. 5(b). In the range of the 63Hz~8000Hz frequency band, the SPL of the ER is reduced by about 10.8dB(A), giving a good sound insulation and noise reduction effect. SO the noise level of ER can be reduced effectively by applying acoustic enclosure to diesel engine.
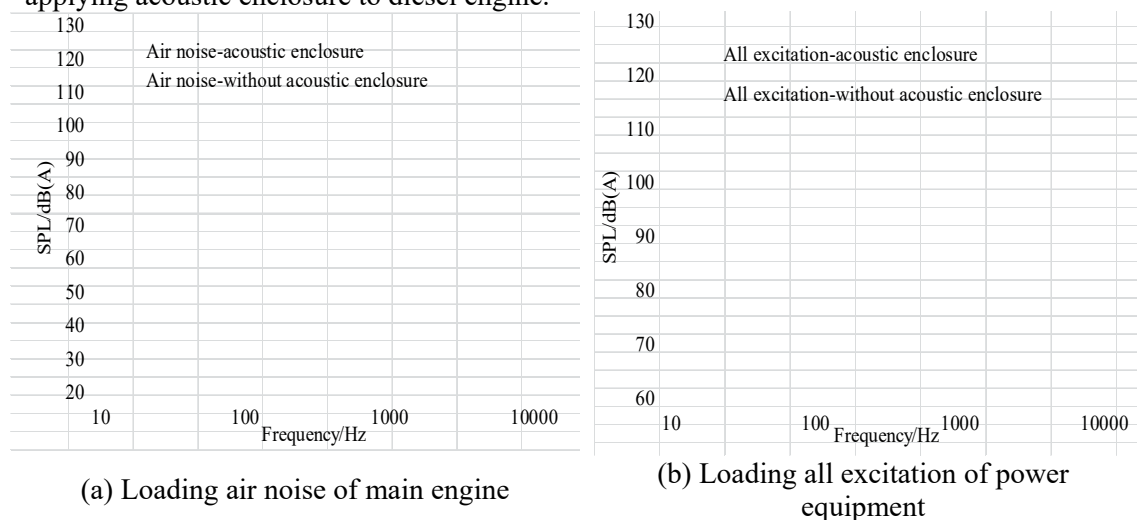

(a) Loading air noise of main engine

(b) Loading all excitation of power equipment

Figure.5 The SPL of the ER under different acoustic enclosure

5. Conclusions

This paper studied the noise prediction of the cruise ship based on the SEA method. The result shows that the maximum noise energy of the cabin is located at the ER, and the energy propagates in the direction of the ship's bow and stern with the ER centered. The noise energy of the receiving cabin is gradually reduced with the increase of distance from the source. The total SPL of ER is close to the IMO standard. By analyzing the contribution rate of different noise sources and the input power of diesel engine structure-borne noise and air-borne noise to ER, the air noise of diesel engine is the main

noise source of ER. Then the acoustic enclosure was applied to the diesel engine, and the SPL of the ER is discussed under the different condition. The study results show that the noise value of the ER is reduced by 36dB(A)~62dB(A) only considering the air noise of the diesel engine, and the sound insulation effect gradually becomes better with the increase of frequency. When all the excitation is loaded, the SPL is reduced by about 10.8dB(A) in the range of 63Hz~8000Hz frequency band, and the acoustic enclosure has good sound insulation effect. So when the air noise is the main noise source, the acoustic enclosure will be a great measurement to control the noise value of the ER.

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