

CONTROL OF RADIATED NOISE FROM SHIP'S CABIN FLOOR

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Abstract

In order to develop the noise control design for a ship's cabin, a series of acoustic tests were carried out by using large scale noise test facilities such as two reverberation rooms and deckhouse mock-up. From the tests, it was found out that the combined noise level of a cabin could be dominated by the radiated noise from the stiffened steel plate system in combination with deck covering and fire-protection insulation, so called the deck floor. In this paper, the dynamic characteristics of a deck floor were fully identified through the structure-borne noise transmission test in the deckhouse mock-up. Based on the results, a variety of countermeasures, such as constrained layer damping treatment, multi-layer floating floor having a visco-elastic damping layer and dynamic absorber, etc., were applied to reduce the radiated noise from the deck floor. The results were compared with those of numerical simulations by using the spectral finite element method. Through a series of numerical simulations and structure-borne noise transmission tests, it was found out that the noise reduction for ship's cabin floor can be greatly enhanced over the entire frequency range if the visco-elastic deck covering is installed between the deck floor and floating floor.

1. INTRODUCTION

In recent years, shipboard noise has become a big issue in ship yards as ship's owners and operators are demanding quieter vessels and relevant noise regulations are getting more stringent. So, a lot of attention has been paid to establish the optimized noise control measures available from the initial design stage. As a rule, however, a ship consists of complex steel structures very weak to the structure-borne noise transmission while she has a number of noise sources, such as main engine, diesel generator, auxiliary machinery, etc. These features make the onboard noise transmissions to be complicated immensely and then make it very difficult to establish proper measures. In order to overcome these problems, several maritime authorities including IMO(International Maritime Organization)[1] have proposed the onboard control methodologies concerning the selection of machinery, isolation of noise sources, sound insulation in accommodation spaces, etc. And, the ship yards have made a lot of efforts to develop the optimized anti-noise design and control technology for ships and to be able to apply the developed technology from the initial design stage.

Among them, the general arrangement of accommodation spaces at the initial design stage is regarded as the essential stage to design the low noise cabin in accommodation. That is, in the viewpoint of noise control, the receiving spaces, such as cabins, offices, mess rooms, etc., are required to be arranged far away from the noise sources. In a container carrier, however, the noise sources, such as engine casing and ventilation fan rooms, are inevitably installed inside the accommodation. So, the receiving spaces adjacent to such noise sources can often experience higher noise levels unless the control methodology available from the initial design stage is exactly established. In order to resolve the problem, the numerical simulation by using SEA (Statistical Energy Analysis) [2] or PFA (Power Flow Analysis) [4~5] may be applied. However, there may still be the limitations to exactly identify the complicated coupling relations in real ships although they have widely used in marine engineering fields because they could model the complex structures with the high accuracy. Accordingly, it is strongly required to conduct the associated tests directly in real ship or indirectly by using large scale test facilities, which can simulate the acoustic environment in real ships. So, by using large scale noise test facilities, such as two reverberation rooms and deckhouse mock-up, a variety of acoustic tests were carried out to exactly develop the anti-noise design and control technology for the cabins adjacent to onboard noise sources in addition to direct controlling the associated noise sources. That is, the sound absorption, transmission and radiation tests for various acoustical materials, including composite panels, such as consisting of stiffened plate, insulation, air-gap, and panel, were conducted in two reverberation rooms. And, the airborne and structure-borne noise transmission tests were performed in deckhouse mock-up having same acoustic characteristics as a real ship.[3] From the tests, it was found out that the combined noise level of cabin could be greatly dominated by the radiated noise from the stiffened steel plate system in combination with deck covering and fire-protection insulation, so called the deck floor.

In this paper, the dynamic characteristics of deck floor were fully identified through the structure-borne noise transmission test in the deckhouse mock-up. Based on the results, a variety of countermeasures, such as constrained layer damping treatment, multi-layer floating floor having visco-elastic damping layer and dynamic absorber, etc., were applied to reduce the radiated noise from the deck floor. The results were compared with those of numerical simulations by the spectral finite element method. Finally, the optimized control methodology was proposed.

2. NOISE TEST FACILITY AND METHOD

In order to develop the low noise design technique for a ship's cabin, a study on the controlling of airborne and structure-borne noise transmissions was conducted by using the large scaled noise test facilities as shown in Fig. 1. The deckhouse mock-up is a two story building for measuring airborne and structure-borne noise transmissions in a ship. The first story simulates ship's engine room and the second story has four real cabins, which are called Lab 1, 2, 3, and 4. The two reverberation rooms were built up of 300mm thick concrete walls in non-parallel pentagonal shape to measure the sound absorption, transmission, radiation, and impact insulation from various acoustical materials, panels, doors, etc. They have two openings of 4.3m by 2.4m for the sound transmission test and 4.0m by 2.5m for the impact insulation test. The volume of each room is 100m³ and 160m³, respectively.

The schematic diagrams for the acoustic tests conducted in two reverberation rooms and deckhouse mock-up are as shown in Fig. 1. The airborne sound insulation of cabin structures was tested to investigate the penetration of background noise during deckhouse mock-up test. It is normally specified by the sound reduction index, R, which was determined according to ISO

140-3 taking into account the reverberation phenomena in the spaces and around the test specimen. The formula is as follows.

$$R (dB) = L_1 - L_2 - 10 \log(S/A)$$
(1)

where L_1 and L_2 are the average sound pressure levels in the source and the receiving rooms, respectively. S is the area of the test floor, which is 10 m². A is the equivalent absorption area in m² in the receiving room, defined according to ISO 140-3.



(a) Reverberation room



(b) Deckhouse mock-up

Fig. 1 Schematic diagram of acoustic test in test facility

At this time, the reverberation time, measured according to ISO 354 and determined using Sabine's formula, is used to find the sound absorption area. The reverberation time for each recorded signal is calculated by integrating its energy using the Schroeder approach. The sound reduction index was finally determined in 1/3-octave frequency bands at least in the range 100...3,150 Hz from which the single-number quantity, or weighted sound reduction index, R_w

is determined according to ISO 717-1. And, the sound radiation test was carried out for the measurement of structure-borne sound insulation. The specimens having a surface area of 10 m^2 , such as double-leaf structures composed of a structural wall and an interior wall, were placed in the opening between two reverberation rooms. An electro-magnetic type actuator was mounted at the center of the structural wall and the constant vibrational power was supplied. At this time, the sound pressure was measured using rotating microphone in the receiving room. The sound power level from the specimen was obtained by

$$PWL(dB) = L + 10\log_{10}A - 6$$
(2)

where L is the averaged sound pressure level and A is the absorption area in the receiving room. In addition, the vibration levels were also measured on the surface of specimen in the receiving room to calculate the radiation efficiency, which is a characteristic frequency dependent number which describes the level of the radiated sound power from a vibrating surface. Finally, the impact sound insulation test was performed in accordance with ISO 140-7. At this time, the tapping machine was installed on the deck floor.

3. NOISE TRANSMISSION IN CABIN

The ship's cabin is generally fabricated with the composite structures such as the wall and ceiling structures consisting of stiffened plate, insulation, air-gap, and panel and the floor structure in combination with stiffened steel deck and deck covering. The typical cabin structure is shown in Fig. 2. Under this condition, the airborne and structure-borne noise transmissions in cabin may be very complicated. So, [3] carried out a variety of acoustic tests by using large scale noise test facilities such as deckhouse mock-up and reverberation room as shown in Fig. 1. Sound absorption, transmission, and radiation properties of cabin structures were quantitatively evaluated and the airborne and structure-borne noise transmissions in cabin were fully identified. The typical result, obtained from when the mechanical source was located below the corresponding cabin, was shown in Fig. 3. In this figure, the noise level of each structure was evaluated by using the transmitted structure-borne noise level at the stiffened steel structure and the reduction of radiated sound power due to internal insulation and panel. Based on the result, it was found out that the floor structure have played a dominant role for the cabin noise level as shown in Fig. 3.



Fig. 2 Typical Cabin Structure



Fig. 3 Comparison of the noise level radiated from the cabin structure

4. RADIATED NOISE CONTROL OF FLOOR STRUCTURE

4.1 Dynamic Characteristics of Floor Structure

In order to accurately find out the dynamic characteristics of floor structure, the structure-borne noise transmission test was carried out in the deckhouse mock-up. At this time, the floor structure was modified according to the measurement conditions. The deck covering, used for the self levelling of the floor as a kind of cement, was firstly removed from the floor structure. It represents 7mm stiffened steel plate structure itself. After that, the deck covering was attached with the different thickness of 4mm to 20mm. Under the test condition, the tapping machine was installed on the top of cabin and moved 5 times for special average. The cabin noise levels were measured and compared respectively. Fig. 4 shows the test results with respect to working conditions. Through this test, it was found out that the deck covering have greatly damped out the noise level around 2 kHz, the critical frequency of stiffened steel deck plate, and the damping effect was gradually increased with the increase of thickness. Below 2 kHz, however, there was little effective. In particular, the noise levels were adversely increased in the low frequency range. It was presumed that such a phenomenon was due to the resonance mode of floor structure. The side effect has gone up with the increase of thickness.



Fig. 4 Comparison of the cabin noise reduction according to the thickness of deck covering

4.2 Various Countermeasures

A variety of countermeasures, such as constrained layer damping treatment, multi-layer floating floor having viscoelastic damping layer and dynamic absorber, etc., were applied to control the radiated noise from the floor structure. Before the application, a series of numerical simulations based on the spectral finite element method[6] were firstly carried out. At this time, the porous material, widely used for the floating floor, was modelled by using the elastic theory[7]. The simulation result is shown in Fig. 5.







Fig. 6 Comparison of the cabin noise reduction obtained from the measurement

Fig. 5 shows that the viscoelastic layer with the steel sheet between the deck floor and deck covering is much more effective compared to the insertion of viscoelastic layer damping only. In order to confirm the effectiveness, the same damping layers were applied in the cabin of deckhouse mock-up. Fig. 6 shows the obtained result. The applied damping layer has revealed to have serious problem in the low frequency range around 100 Hz although it was very effective in the high frequency range above 1k Hz as shown in Fig. 5. This phenomenon was increased much more when the floating floor, consisting of the 50mm mineral wool with high density and 5.0mm sandwich steel plate with the viscoelastic layer, was installed. However, the

case having the viscoelastic deck covering below the floating floor wasn't largely deteriorated. Furthermore, the noise reduction level in mid-high frequency zone was highly increased. Based on the result, the optimized multi-layer floating floor structure was proposed. As shown in Fig. 5, it was predicted that the performance could be greatly enhanced over the entire frequency range. In addition, the dynamic absorbers were applied on the floor structure to absorb the radiated noise in the low frequency range. As shown in Fig. 3, however, they didn't work very well because the noise contribution due to the floor structure was not much bigger.

5. CONCLUSIONS

In order to effectively reduce the radiated noise for the floor structure, a series of numerical simulation and acoustic tests were carried out. Based on the result, it was found out that the capacity of noise reduction might be greatly enhanced over the entire frequency range if the viscoelastic deck covering would be installed between the deck floor and floating floor.

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