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Study on Noise and Vibration Prediction and its Reduction Design in Ro-Ro Passenger Ship

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Abstract

Noise and vibration on board ships produced by the operation of ship machinery and equipment generates a huge challenge for crew and passengers. Control of noise in ship cabin presents an important project criterion worth studying. Maintaining noise and vibration levels within standards of IMO ensures adequate comfort onboard ship crew. To control noise under IMO standards, fast-modelling strategies for cabin noise level based on SEA is proposed. By using Vibro-acoustic software (VA-one), an acoustic design of a RO-RO passenger ship is demonstrated.Application of appropriate noise and vibration isolation materials, control treatment and vibration isolation treatment, noise levels within the ship is recorded and analyzed. Analysis show noise levelson enginedecks were not in tune with standards provided by IMO, therefore mechanical vibration materials were used to insulate the decks, results show a noise reduction of 12dB(A). The cabins were also insulated with sound absorbing materials firmly held together using adhesives, application of the sound absorbing material show a noise reduction of 3~8dB(A). The application of the noise reduction techniques on engine decks and in cabins show an overall noise reduction of 3dB (A) ~ 12dB (A) which falls within acceptable noise level limits of 2014 IMO standard.

Keywords: Noise level, Vibration, Statistical Energy Analysis (SEA), Noise Control in Ship Cabin, Reduction, RO-RO passenger ship, International Maritime Organization (IMO), Vibration Isolation Treatment (VIT)

1. Introduction

Noise and vibration onboard ships due to marine machinery and equipment is of a huge concern to crew, passengers and the entire shipyard environment. The acoustic discomfort has many adverse effects on people as it causes disturbance and irritations during sleep periods. Prediction of noise levels on ships is a growing concern for ship owners and passengers. This is particularly true for passenger ships, as the acoustic level criterion is of great importance for cruise ship customers in relation to their comfort. Merchant ships also frequently encounter noise and vibration problems as structural acoustic effects and noise are often omitted during design. Hence, noise levels need to be kept within the prescribed limits to provide adequate comfort for crew and passengers. Noise on board Ro-Ro passengers ship is of great concern due to its relatively high installed capacity, it is therefore necessary to make a noise forecast at the initial stages of the ship design in other to reduce the acoustic deficiencies and reduce cost associated with controlling noise and vibration levels.

There are a number of sources of vibration and noise present on board ships(Carlton & Vlasic, 2005).Some typical sources are engines, shaft-line dynamics, and propeller-radiated pressures and bearing forces, maneuvering devices such as transverse propulsion units, air conditioning systems etc. when generated, and noise propagates within the ship in various ways. Airborne sound radiated by a source may be transmitted through walls, bulkheads and decks. At low frequency, noise transmission occurs as a result of membrane vibration of the structure, but at high frequency, it has wave characteristics. Sonic form of vibration is transmitted through the foundation floors and hull structures, with subsequent radiation of airborne sound in neighboring and remote compartments. In the case of machinery in which the vibration energy is produced in the form of sonic vibration (pumps, compressors, diesel engine), noise in neighboring and remote compartments occurs mainly due to the latter type of sound transmission. This is evident in situations when machinery is mounted on relatively light foundations in compartments with good airborne noise isolation. Effects of noise in ship compartments remote from the source of vibration is mostlythrough transmission of sonic vibration in the hull structure.

In the marine industry, although noise prediction and reduction measures have been adopted on certain categories of vessels, such as luxury cruise liners and government-owned research vessels, there are also many categories of vessels in which noise reduction is made difficult by structural factors, such as the location of passenger cabins adjacent to an engine room or engine casing(Lois, Wang, Wall, & Ruxton, 2004).However, with the introduction of noise regulation for the interior of vessels introduced by the International Maritime Organization (IMO) in July 2014(Badino, Borelli, Gaggero, Rizzuto, & Schenone, 2014).that extend strict noise restrictions to ordinary commercial vessels based on their international gross tonnage, noise minimization requirements become a huge concern in the marine sector. According to the noise level code of July 2014, the IMO standard proposed noise level limit in accommodation spaces be decreased 5 dB (A). This situation therefore makes noise prediction and reduction with high accuracy a must measurement to comply with during the design phase. In general, cabin noise signals comprise not only low frequency discrete spectra due to rotating and reciprocating machinery but broad continuous spectra due to ventilation systems, propeller noise, and other resource. To address the broad characteristics of cabin noise, finite element method (FEM), boundary element method (BEM), and statistical energy analysis (SEA) are mainly the methods currently used to control noise levels in ship cabins. In recent years, many researchers have used statistical energy method to perform noise prediction analysis on relevant ship cabins. Hideyuki *et al*, (Shuri, 2016)conducted a research on noise prediction in a ship using vibration and acoustic data from shipbuilders and results show that 5 dB (A) ~ 10 dB (A) noise was reduced at frequencies lower than 160Hz, results also shows that noise from other parts of the ship contributed to high noise levels in the cabin other than the main engine and diesel generators. (Changjian, 2001)conducted a research on cabin noise control using a large oil tanker, they proposed two measures to carry out noise and vibration control in ship cabin using methods such as floating floors on all decks and sound absorption material within exhausts channel, the result show a reduction effect of about 2.9 dB (A) ~ 4 dB (A). Huabing wen *et al*,(Fang, Wen, Liu, & Dong, 2013)conducted a research on the prediction and control of 32m Z-propeller Tug cabin’s vibration and noise, they proposed some solutions to vibration and noise control by using techniques such as sound absorbing materials and mechanical vibration isolation, their results show a noise reduction of 7 dB (A) in meeting room and 5 dB (A) in engine room. In this paper, we describe the theory of SEA model and then apply the SEA technique to calculate the noise levels on board a RO-RO passenger ship (OM-ZGX21506-303-001), showing results of acoustic noise reduction within cavities and plate elements.

2. Theoretical Analysis of SEA

Most of the basic ideas of SEA are derived from the study oftwo coupled sub-systems. Conclusions made for such systemsare then generalized for cases that are more complex. SEA has a long tradition, as the earliest works in the development of statistical analysis of models which emphasis on energy propagation by Lyon *et al*. date back to the 1960s(Lyon & Scharton, 1965),(Lyon, 1970),(Dowell & Kubota, 1985). Following them. A number of references appeared in order to contribute to the improvement of the theory, like(Burroughs, Fischer, & Kern, 1997),(Yan, Parrett, & Nack, 2000),(Hopkins, 2002),(Sheng, Wang, Sun, & Qian, 2004). Commercial software tools based on SEA are available (Ballou, 2015).

Most of the basic ideas of SEA are derived from the study oftwo coupled sub-systems. Conclusions made for such systemsare then generalized for cases that are more complex. Considering coupled subsystems and their energy flow, as indicated in Figure 1. Each subsystem may be driven, both dissipateenergy, and there exist a conservative interchange of energybetween them. Considering in a long time span, the averages oftheir energies are related as:

$$\langle \Pi_{1diss} \rangle = \langle \Pi_{1IN} \rangle - \langle \Pi_{12} \rangle \tag{1}$$

And

$$\langle \Pi_{2diss} \rangle = \langle \Pi_{2IN} \rangle - \langle \Pi_{2.2} \rangle \tag{2}$$

Where angle brackets denote long-term time averages of dissipated, Π_{idises} input, Π_{iIN} and exchanged Π_{12} and Π_{21}, energyflow of the $i^{\text{-th}}$ subsystem. E_{itot} represents total amount of energy (kinetic and potential) contained within one system. Theexchanged energy flow is related as $\langle \Pi_{12} \rangle = -\langle \Pi_{21} \rangle$, as long as the assumption of conservative coupling between subsystems is valid.

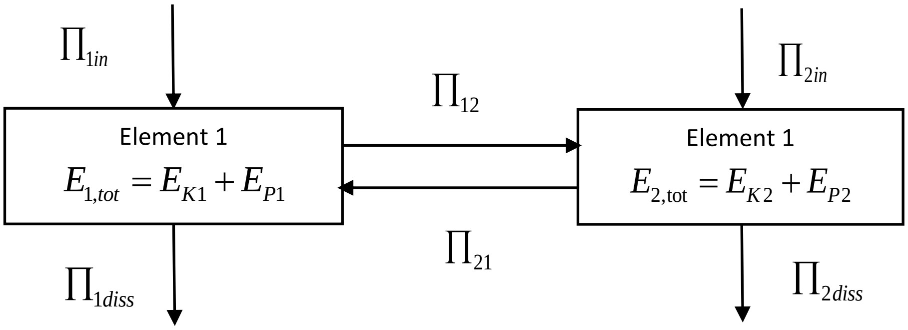


Figure.1 Energy sharing by two coupled systems models

When the complex structure system is divide into N couple subsystem, the energy balance equation is expressed as the following formula.

$$\omega\begin{bmatrix} \eta_{1,tot} & -\eta_{21} & -\eta_{31} & \cdots & -\eta_{N1} \\ -\eta_{12} & \eta_{2tot} & -\eta_{32} & \cdots & -\eta_{N2} \\ -\eta_{13} & -\eta_{23} & \eta_{3,tot} & \cdots & -\eta_{N3} \\ \vdots & \vdots & \vdots & & \\ -\eta_{1N} & -\eta_{2N} & -\eta_{3N} & \cdots & \eta_{N,tot} \end{bmatrix}\begin{Bmatrix} E_{1.\text{tot}} \\ E_{2.tot} \\ E_{3.tot} \\ \vdots \\ E_{N,tot} \end{Bmatrix} = \begin{Bmatrix} \dfrac{\Pi_{1,in}}{\omega} \\ \dfrac{\Pi_{2,in}}{\omega} \\ \dfrac{\Pi_{3,in}}{\omega} \\ \vdots \\ \dfrac{\Pi_{N,in}}{\omega} \end{Bmatrix}' \qquad (3)$$

Where, ω is the center frequency of the calculating band η_N is the damping loss factor the subsystem, n_N in the number of system modes in the frequency band, E_N is the vibration energy of the subsystem. The energy of each subsystem can be obtained by solving this equation. In addition to the energy the acoustic vibration environment of the whole system can be predicted.

There are four important parameters in SEA model such as,

Modal density Modal: Is defined as the number of models per unit frequency. As a physical quantity that measures the ability of storing acoustic vibration energy, it is also a very important parameter in the SEA method.

Power input: The power input from the external excitation is an important SEA parameter; in general, three types of the power input are studied which are point sources, line sources and area sources, respectively.

Damping loss factor: Damping loss factor represent the rate of energy lost against energy stored per unit frequency. Damping loss factor comprises of structural loss factor, boundary friction loss factor and acoustic radiation loss factor.

Coupling loss factor: The coupling loss factor represents the energy dissipation between two coupled subsystems; it is used to measure the level of coupling among subsystems of the complex structure.

3. Ro-Ro passenger ship parameters and noise source in ship cabin

The Ro-Ro passenger ship (OM-ZGX21506-303-001) is a modern Car passenger ferry, its length is around 190m, vertically divided into ten decks from the tank top to the wheelhouse level. Two shafts are fitted with CP propellers and driven by four coupled medium speed diesel engines in other to achieve propulsion. The main design parameters of Ro-Ro passenger ship are presented in Table. 1

Table.1 Overall dimension of the Ro-Ropassenger ship and its capacity.

Length O. A	188.90m
Length B. P	171.50m
Breadth (MLD)	28.60m
Dead weight	7500t
Gross Tonnage	33500t
Engines modal number	Wartsilla 9L32E2 4Sets
Number of engines	4
MCR	4*5220KW
Number of diesel generator	4
Service speed 4*4080KW, 100%	20.6 Knots
S.M shaft generator	
Endurance	4000n.miles
complement	950P

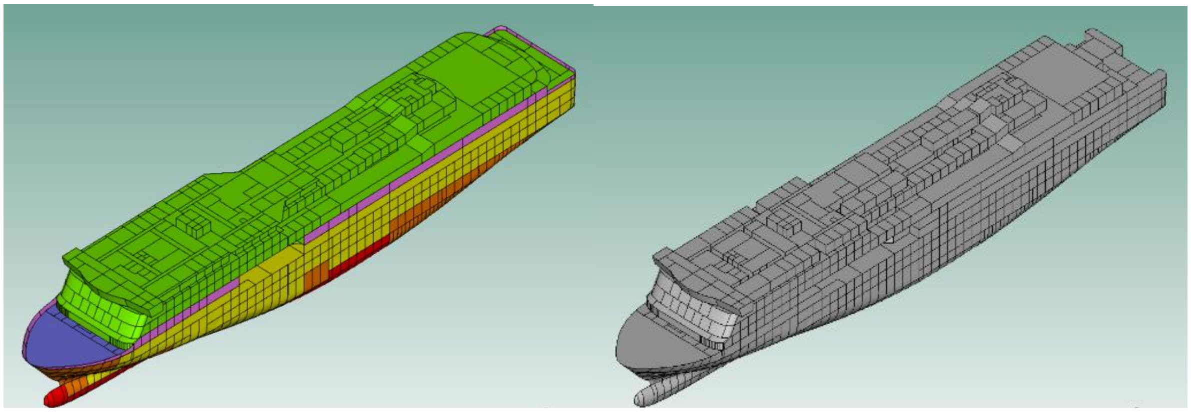
The air-borne noise and structure-borne noise occur due to diesel engines, propeller and auxiliary equipment’s are also considered as major sources of cabin noise. In addition, the emission of noise from the exhaust chimney and the ventilation fans in the engine room have great impact on the noise levels in cabin.

3.1 Noise and vibration transmission path analysis in ship structure

Structure-borne noise and air-borne noise are two major mechanisms for cabinnoise. When the main engines and auxiliary equipment’s are operating, their vibration istransmitted from the engines, via isolators, supporting bases, and bulkheads, etc., to the shellstructures throughout the entire ship. This is called structure-borne path, along which, the vibration energy can flow from the engines to other parts throughout the ship. As a result, cabinnoise is produced. As for the air-borne noise, the air within the cabins act as elastic components through which vibration and sound energy is transmitted to adjacent cabins.It is also noted that, from the of structure-borne noise viewpoint, waves can propagatefreely within the plate and shell structures until they encounter discontinuities such as thejoins and junctions. Reflection would occur at these discontinuities, which makes the effectiveness of vibration transmission path change significantly.

3.2 SEA model of Ro-Ro passenger ship

The numerical approach is built using VA-one software. The popular finite element method cannothandle this situation when the dynamic systems possess high modal density and have uncertainty in modal parameters. Hence, in our cabin noise software, Statistical Energy Analysis(SEA) model is used. The figure 2.a show the plate subsystem model of Ro-Ro passenger ship displaying all decks and the figure 2.b show the acoustic model of Ro-Ro passenger ship.



(2.a) The SEA plate model (2.b) The acoustic model

Figure.2 The model of RO-RO passenger ship

The SEA allows for a much straightforward description of the ship system, in which the entiredynamic system is partitioned into several subsystems, each can be explicitly represented byinternal energy, coupling loss factors, and internal loss factors. The internal energy of the subsystems is a function of modal densityand major geometry parameters. Thedissipated energy can also be determined throughtransmission loss at the junctions and internal damping.

4. Noise and Vibration prediction result in RO-RO Passenger Ship

The Figures 2.a-b show the intended designed foundation steel plate and the acoustic model of a Ro-Ro passenger ship using the VA-ONE software, SEA stimulation is used to compute the foundation by applying a force on the foundation plates, the calculations are done by the software using a frequency range of 62.5 Hz to 8000Hz in the low frequency range. Considering the SEA model above, a numerical calculation is performed. The cabin noise levels at different positions is calculated. Numerical calculations performed below are based on SEA model. Cabin noise levels at different locations on board the Ro-Ro ship are listed in Table 2. Analysis from the Table.2 show sound pressure levels at some locations being above the limits derived by IMO.To better illustrate the predicted sound levels insome accommodation spaces, sound levels are shown in Figures 3 to 6.

Table.2 Cabin noise level result for RO-RO passenger ship.

Deck	Location	Prediction simulation value dB (A)	Limit IMO standard dB (A)	evaluation
Deck 1	Engine room rear	113.60	110	None
	Engine room front	114.78	110	None
	Engine room control	80.12	75	None
Deck 2	Workshop deck 2	78.43	85	Yes
	Windlass control room/bonus's store room	49.23	70	Yes
Deck 3/4	Meeting room deck 5	62.02	55	None
Deck 6	Quadruple room 6116	58.47	55	None
	Double room 6133	56.41	55	None
	VIP room 7102	45.11	55	Yes
Deck 7	Quadruple room 7223	55.38	55	None
	Passenger galley/kitchen	61.67	75	Yes
	VIP suit 8101A	45.36	55	Yes
	Captain cabin	49.26	55	Yes
Deck 8	Wheel house	44.64	65	Yes
	Meeting room	51.82	55	Yes

deck 9	Chief engineer cabin	50.95	55	Yes
	Chie off cabin	51.12	55	Yes
	Polite cabin	55.43	55	None
	Single room 9109	55.76	55	None
	Recreation room	48.87	60	Yes
	Hospital/medical cabin	51.88	55	Yes
	Double room 9223	55.48	55	None

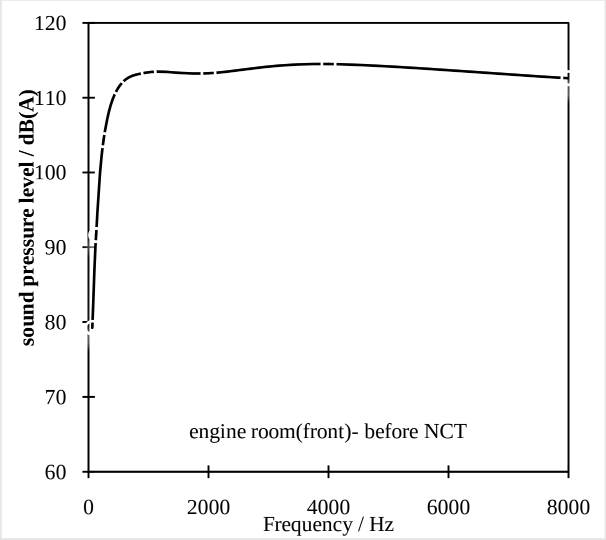


Figure.3 Sound pressure level of engine room front before noise control treatment

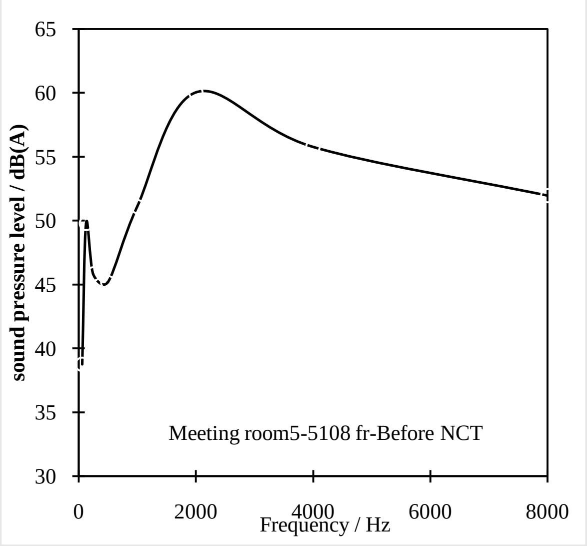


Figure.4 Sound pressure level of meeting room5-5108 before noise control treatment.

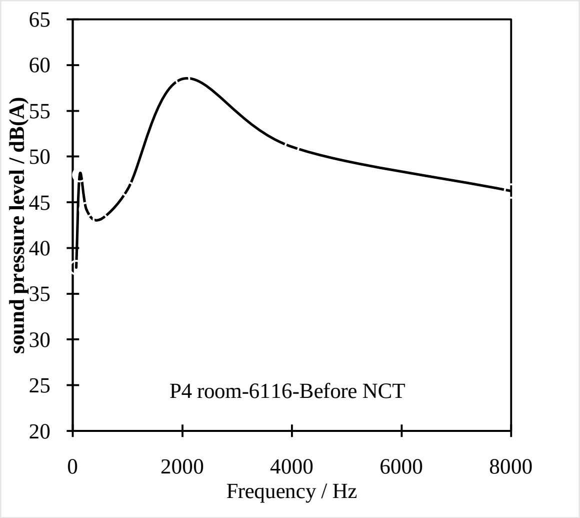


Figure.5 Sound pressure level of P4 room 6116 before noise control treatment.

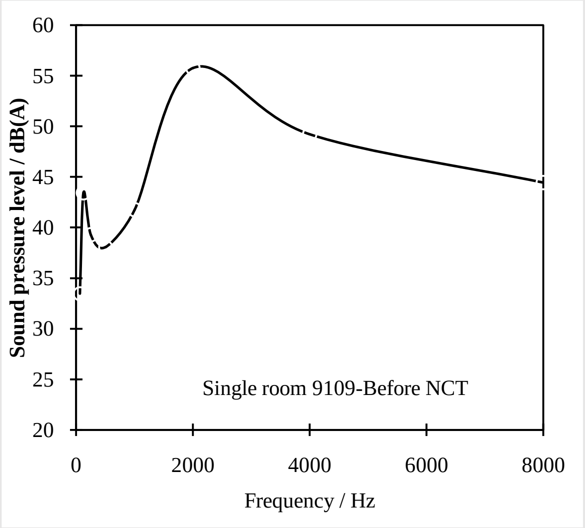


Figure.6 Sound pressure level of single room 9109 before noise control treatment.

According to the Table.2, noise levels in some accommodation spaces, cabin and office spaces cannot meet the requirements of IMO noise levels limit [3]. The results show that the noise prediction error of cabin is more than 8 dB (A). In section 6, specific materials will be used to reduce the noise level further.

5. Noise Level and vibration control in Ro-Ro passenger ship cabin

The results presented in Table 2 indicate that the value of the noise level in some locations such as: Meeting Room 5108, Engine Room and cabin No 6116 exceeds the allowable values of the IMO. This implies that changes should be made on the preliminary design to lower the sound levels at these locations. Several recommendations of noise control measures have been proposed in the updated design. As diesel engines and auxiliary equipment's are the main vibration source of noise in RO-RO passenger ship. To reduce these problems, a single-layer of mechanical vibration isolation design is adopted. Mechanical vibration isolation is part of the most suitable technology used to reduce the vibration and noise on board ships. Analysis of several vibration isolation devices commonly used in the area of ship vibration and noise reduction, a single-layer vibration isolation system using ten AV/C2S vibration isolators each was adopted and applied to the diesel engines. After single-layer vibration isolation measures are taken on the engine deck, the vibration of the hull structure and cabin noise level caused by the vibration of the main engine and equipment is reduced. Table.4 and figure.7 compares the sound pressure level within the engine room front before and after vibration isolation. The average noise level effect is close to 12 dB(A). The noise level drops from 114.78 dB(A) to 102.80 dB(A) and is in accordance with the allowable standard values of IMO.

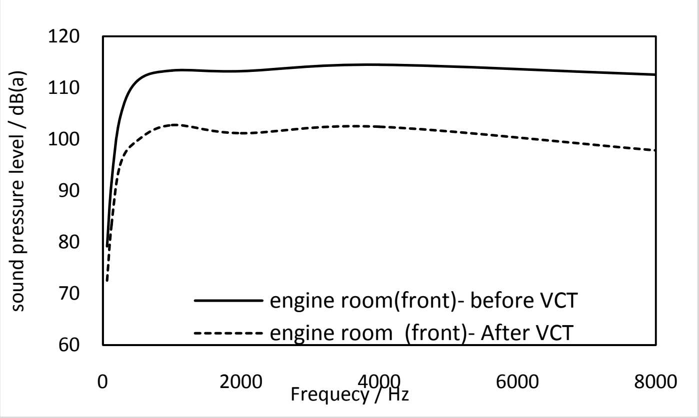


Figure 7. Sound pressure level of engine room front before and after noise vibration isolation treatment.

Noise and vibrations produced by the engines and axillary equipment are transmitted directly into accommodation spaces such as cabins, meeting rooms etc. To reduce these noise and vibration problems, a multi-layer designed sound absorption material is adopted, the first layer is polyurethane foam of thickness 40mm, and the second layer is a fiberglass material of thickness 20mm. These two materials are coupled to form a sandwich layer and compared at frequencies near the peak frequency of 8000 Hz of cabin noise within a relatively wide frequency range. The multi-layer sandwich material is placed on the bulkheads of the meeting room and the accommodation room using an adhesive. Simulation of the noise and vibration results of the sound pressure are shown in figures 7 and 9 and in Table 4. The noise and vibration levels in high frequency range is reduced after the application of the multi-layer sandwich sound absorption material with an average noise reduction level of 10.45 dB(A) for the meeting room number 5108 and 11.30 dB(A) for single room number 6116. The noise level drops from 62.02 dB(A) to 49.59 dB(A) for meeting room from 58.57 dB(A) to 47.27 dB(A) with results values ranges in accordance with the allowable noise and vibration level values rightly within the IOM acceptable standard.

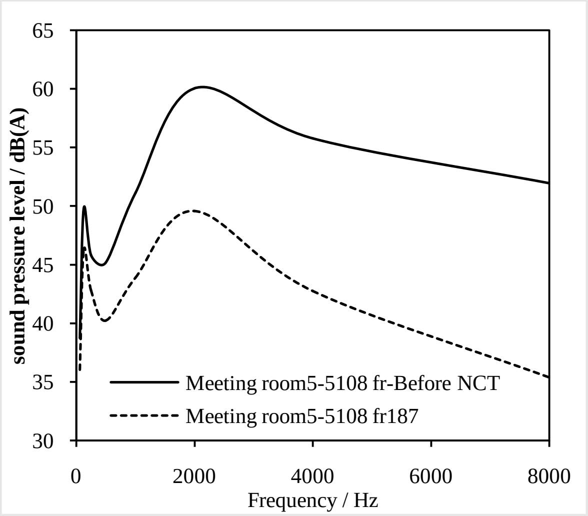


Figure 8. Sound pressure level of meeting room5-5108 before and after noise control treatment.

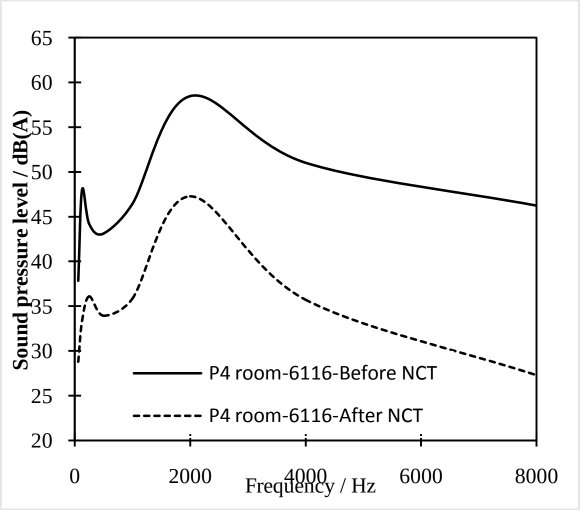


Figure 9. Sound pressure level of P4 room 6116 before and after noise control treatment.

Tabl.3 cabin noise control on RO-RO passenger ship. dB (A)

Deck	Location	Before NCT dB (A)	After NCT dB (A)	IMO standard dB (A)	Noise reduction effect
Deck 1	Engine room rear	113.60	101.60	110	12
	Engine room front	114.78	102.8	110	11.98
Deck 5	Meeting room deck 5	60.04	49.59	55	10.45
Deck 6	Quadruple room 6116	58.57	47.27	55	11.30
	Double room 6133	56.41	48.60	55	7.81
Deck 9	Single room 9109	55.76	49.91	55	5.85

6. Conclusion

In this paper, the noise levels for a Ro-Ro passenger ship used for transporting more than 950 passengers and cars is calculated. The research task was to determine the noise level for each section of the Ro-Ro ship and to apply noise and vibration reduction measures to reduce high noise levels which didn’t fall within prescribed IMO standards. In using the SEA model in the VA-one software package, the acoustic noise is efficiently optimized. The results of the noise prediction enable high-quality noise analysis to be conducted at an early stage in the shipbuilding design in other to improve the selection of equipment, materials, noise control measures etc., for the standard noise level requirements to be met. In line with the above-mentioned program package, the paper outlines the basic issues related to noise in technical systems with an emphasis on ships. The legal regulation in the field, as well as the contemporary numerical noise analysis methodology, have been analyzed. With regard to the analyzed model of the ship, it can be inferred from the obtained results that, for the spaces occupied by the passengers, noise levels can be reduced with the localized use of appropriate sound insulation. The study described in this paper shows that a noise reduction effect of about 11dB(A) can be attained by fitting a constraint type acoustic absorption material in the cabin. Moreover, a noise reduction effect of about

12dB(A) can be attained by usingmechanical vibration isolation material on the main engine deck in the engine room. The analysis shows a noise and vibration reduction effect of about 3dB(A) ~ 12dB(A) can be attained by using sound absorption and insulation materialson the engine decks and bulkheads of the cabins. Consequently, it was concluded that a noise reduction effect of about 3dB(A) ~ 12dB(A) can be attained by implementing two measures which reduces the acoustic noise levels to meet the requirements of the 2014 IMO standard.

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