The application of new noise and vibration standards onboard ships

T Pazara¹, M Pricop², G Novac³ and C Pricop⁴

¹Professor Assistant, PhD, Naval Academy „Mircea cel Bătrân”, Constanța, RO
²Associate Professor Eng., PhD, Naval Academy „Mircea cel Bătrân”, Constanța, RO
³Professor Assistant, PhD, Naval Academy „Mircea cel Bătrân”, Constanța, RO
⁴Associate Professor Eng., PhD, Maritime University, Constanța, RO

¹tiberiu.pazara@anmb.ro
²mihail.pricop@anmb.ro
³george.novac@anmb.ro
⁴pricopcodruta@yahoo.com

Abstract. The ship represents a very complex system of noise and vibration sources determined by the operation of numerous onboard installations and specific activities of crew and passengers. Shipboard noise can cause discomfort to passengers and hearing damage to the crew and in this regard the need for a safe work environment is growing. Due to these effects, it is necessary to strictly observe the noise and vibration criteria by noise and vibration analysis in the design phase and their adequate control. In this paper are discussed the aspects regarding the latest standards of noise and vibration for ships. It is well known that changes made in regulations are not easy to be implemented on board old ships. The authors made a careful analysis of these changes and made a few recommendations for the shipbuilding companies and naval operators.

1. Introduction

The progress in naval industry is associated with changes in naval standards and one of these standards regards the comfort onboard ships. On commercial ships is important to assure a safe environment for the crew. A criterion is represented by the noise and vibration to which the crew is exposed Jegaden [1,2]. During the years, national and international organizations established limits for noise and vibration exposure. These limits changed over the years due to observations and studies made to improve the conditions of the crew onboard.

In 1981 the IMO organization set the standards for noise and vibration onboard ships. Since then, numerous studies and research made observations and conclusions that improved the conditions of navigator’s onboard commercial and military ships. DNV, IMO, ABS and other organizations collect information and update the standards. Due to globalization, these standards cannot vary from country to country. The need to assure a uniform standard and in the same time to protect and preserve the safety and the health of the crew have determined a continuous upgrade of the noise and vibration limits.

In time, the noise and vibration criteria have been established for civil and military ships. For civil ships, there are standards for cruise ships and commercial ships. This means that nowadays three different sets of rules are in effect. Of course, the limits don’t vary that much from one standard to another but it is important to apply these standards onboard every ship regardless of its type.
Biot and de Lorenzo [3] studied the applicability of noise and vibration criteria onboard cruise ships. They have pointed that the changes in ISO 6954:1984 that were made in 2000 (ISO 6954:2000) do not cover all the aspects of the problems. Their conclusion was that changes must be made carefully with consideration to human perception of noise and vibration.

In 2009, the IMO Sub-committee on Ship Design and Equipment made proposals to improve the noise criteria onboard ships [4]. Approximately, for each type of compartment these proposals suggest a 5dB reduction of noise limits. In the following years, specialists from different countries analyzed the proposals and concluded that these exposure limits must be applied Shuri 2010 [5] Kitamura 2010 [6], Yudong 2010 [7]. But in November 2012, the MSC-337(91) [11] was adopted without a part of specialists’ amendments. Beltran et al [9] pointed that very small changes have been made from the old standard and the protection of the crew is not improved.

Constructors and shipyards must implement these standards onboard ships. S-H Kim [10] presented a few improvements that Hyundai Heavy Industries have introduced onboard their ships according to ISO standards. However, these improvements were made only on new ships and not on old ships. For ship, builders the new noise and vibration criteria can easily be applied onboard their new projects. The challenge for the ship owners is to implement the new limits to their current sailing ships.

2. Sources of noise and vibrations on-board ships

In this paragraph are presented some of noise and vibration sources and a few solutions to reduce their effects.

2.1. The main engine

Noises and vibrations due to the structure

Solutions:
- Main engine adjustments by minimizing imbalance to avoid any further noise transmission.
- Operation the main engine in the proper mode: whenever possible revolutions and propeller pitch must be adjusted in order to reduce noise and vibration.
- A correct alignment of main engine, gear and shaft is needed

Noises and vibrations due to the engine mounting

Solutions:
- Flexible mounting of main engine with: engine is placed on vibration absorbers designed against increased dynamic and axial load; between main engine and gear must be fitted a flex-coupling; It is necessary to ensure that the bed-plate is rigid as the engine is not a part of the rigidity.

Air borne noise radiation

Solutions:
- Sealing the engine: if the main engine is the main noise source it is necessary to seal the engine, a solution that requires a lot of space around the engine; this measure must be combined with flexible mounting of the engine and it’s also important to ensure adequate cooling air presence with absorbing labyrinth openings; all lead-ins must be tightly and flexibly sealed.
- Sealing engine room from noise penetration: when sealing the engine room all surfaces must be insulated (rock wool and galvanized sheet) and lead-ins and component mountings also.
- Absorption panels for noise reduction in engine room: by hanging absorption systems for reduction of the reverberation (the system must not absorb oil fumes);
- Packings in doors and openings: by mounting close-fitting rubber profile packings in doors or in hatches.

2.2. The exhaust system

Noises and vibrations due to the structure

Solutions:
• General solutions: by removing all fixed spots between structure and exhaust system; the expansion joints must never be fully compressed or extracted; the exhaust system with absorber must not hang in or be supported by expansion joints;
• Mounting sound absorber: sound absorbers can be mounted on rubber or full-metal absorbing elements;
• Exhaust pipe with rain cap: by mounting a fixed rain cap with overflow and coming on top of funnel (the funnel top must not touch the exhaust pipe).

Air borne radiation
Solutions:
• Insulating sound absorber and pipes: by insulating and sealing the suspension, flanges and expansion joints of exhaust pipe and sound absorber;
• Providing new sound absorber: by placing a high efficient sound absorber with new absorbing features made specifically for individual vessel;
• Exhaust system tuning: avoid any resonance by tuning the entire exhaust system;
• Casing insulation: by insulating surfaces towards accommodation spaces.
• Mounting baffles in casing: mounting sound baffles or insulating of side sections will reduce standing sound waves and noise from the exhaust system (it is necessary to ensure free air flow).

2.3. The propeller
Effects on the structure due to the cavitation
Solutions:
• New or modified propellers: using wake field adapted new propellers or nozzle propellers;
• By changing blade tilt: blade tilt with low-noise shape (can affect on drawing power).
• Improve the area above propellers by:
  - Reinforcing the hull plate above the propellers by means of bracing and/or thicker plates;
  - Mounting vibration reduction system material on hull plate above propellers and on deck;
  - Using absorptive material in rooms with reverberation;
  - Placing cement in hull plate area above propellers.
• Insulating the engine room towards propellers: by Insulating hull plate and abaft bulkhead;
• Placing of zinc: in order to avoid unnecessary eddy currents around propellers zinc must be placed in current paths

Effects on the structure due to the noise from nozzle
Solutions:
• Nozzle shaft reinforcement: the hull nozzle shaft must be fixed and efficiently mounted and also the soft plate areas must be strengthened.

2.4. Auxiliary engines, pump and other equipments
Effects on the structure due to machinery mounting
Solutions:
• Ensuring a solid foundation: pumps and engines foundation must be rigid and thoroughly mounted to the construction;
• Using absorbers: machinery must be placed on rubber absorbers/mats.

Effects on the structure due to connections
Solutions:
• Using flexible connections: using whenever possible only flexible connections when mounting a component flexibly.
Air borne radiation from components
Solution:
- Better sealing: using sound absorbing case for components to mount in without ignoring heat release or cooling air;
- Shielding: if sealing is not possible the use absorptive panels.

2.5. The pipe system
Effects on the structure due to pipe diameter, suspension or rigidity, pipe penetration
Solutions:
- By changing the pipe dimensioning: enlarging the pipe diameter for high speeds or pressure;
- Flexible mounting of pipes: using suspended flexible brackets or rubber lining brackets;
- Using u-bend mounting for Long rigid pipes; pipes must not be attached to two fixed points without the ability to move.
- Using waterproof lead-ins: If possible use flexible lead-ins or ensure that the pipe is not both sides fixed;
- Using open lead-ins: make sure that the pipe does not clank and is free from the opening.

2.6. The hydraulic system
Effects on the structure due to piping/suspension
Solutions:
- General solutions: avoid using sharp elbows and transitions and also avoid using straight pipes between two structure fixing points; suspension must be flexible whenever possible and flexible connections used at bulkhead lead-in, engine and pump.
Effects on the structure due to pressure deviation or speed
Solutions:
- Using sound absorber in the high pressure system;
- Using pressure accumulator in substantial pressure deviations systems;
- Increasing pipe diameter when using high or many pipe bending.
Effects on the structure due to hydraulic engine
Solutions:
- Using suspension: by suspending with absorbers and flexible connections (hose connections).

Air borne noise from hydraulic engine
Solutions:
- By sealing: installing components in an airproof box without ignoring heat release or cooling air;

2.7. The ventilation system
Effects on the structure due to air duct rumble
Solutions:
- Making reinforcement: using cross bracing of plate areas or bending the plates in pyramidal shape;
- By silencing mass: adding silencing mass on plate area (bitumen plates or coating);
- Lowering air speed by using larger duct;
- Sleek Transitions by avoiding sharp elbows and large changes in cross cut.
Effects on the structure and air borne noise due to ventilator
Solutions:
- Making modification: using flexible suspension of ventilator, changing number of revolutions or replacing the rotor.
- Using new ventilator with low noise level.
Air borne air noise in duct
Solutions:
- Avoid tearing by using absorptive material with thin plastic coating to;
- Mounting sound absorbers in the air ducts;
- Lowering air speed by enlarging the duct cross cut or increasing the air ducts number.

Air borne air noise in blow-off and air diffusion
Solutions:
- Using silenced blow-off valve with larger openings to reduce opening speed;
- Using baffles inside air intake grill;
- Making larger opening: a larger air intake grill with smooth transition to air duct will cause an intake speed reduction.

3. Case study: noise on-board training ship Mircea

Although is not a ship from one of the three categories mentioned in paragraph 1, training ship Mircea must comply with the standards regarding noise and vibration. We chose this example because we want to see if the new standards can be applied onboard an old ship. For this purpose, a set of measurements were taken during a short voyage in the Black Sea. The noise was measured with a sound level meter B&K type 2250. In the following figures (1-5) are presented the noise levels measured in several compartments.

![Figure 1 Second officer room](image-url)
Figure 2 Command deck

Figure 3 Storage compartment
Figure 4 Machine room

Figure 5 Open deck
By comparing these results with the noise limits imposed by [MSC-337(91)–11] we can observe that these limits are exceeded. Of course, the differences are little, but due to extended time of exposure these noise levels are not acceptable onboard. Comparing the measured noise levels with the old standard [12] they comply only for the machine compartment.

4. Conclusions

From the design and construction phase of the ship's body the sources of noise and vibrations are analyzed in terms of energy level, frequency spectrum, their interaction with the structure of the ship, air and water transmissibility, as well as effect on receptors (crew members and passengers). Due to the increase in ship size and the power of propulsion installations for increasing comfort in passenger ships, the criteria of international standards on acoustics and vibrations have been introduced over time in the naval field, globally approved by the regulations for limiting the noise level and vibration on ships [1].

The ship is a complex construction in terms of both of the metal structure and numerous machines, equipment and installations used for good efficiency. All of these items are sources that emit noise and vibrations in air and water, with special effects on humans, fauna and environment.

The main engine and auxiliary engines generate noise and vibration in air and structure in which they are fixed. The frequencies of these signals are determined by the speed of rotation, the number of cylinders, the number of cycles, the crankshaft, the number of piston valves or the number of piston rings [1].

The propeller is the second source of noise and vibration, which propagates in water and inside the hull. The phenomena that produce these noises and vibrations are more complex than in the case of thermal machines and are determined by the cavitation, the variation of the pressure around the propeller due to suction and rotation of liquid inside the propeller [13, 14].

Also, the ship's wake has a very large influence and is determined by the unevenness of the current in which the propeller operates as direction and amplitude [15].

Air conditioning, ventilation and air conditioning are also sources of noise. The structure of the body (deck, walls, ceilings), pipes and tubes that vibrate, also become noise sources in the spaces occupied by passengers and crew [16].

Depending on the type of ship, mainly loading / unloading and handling equipment on board (grapples, conveyors, vehicle ramps, etc.) there are also other sources of noise and vibration [17].

Because of these noise and vibration sources, the air and water propagation pathways, the phenomena of reflection, diffraction, absorption, dispersion and subjectivity of the receptors (crew and passengers) at different times of co-existence on board the ship (in a state of recurrence / rest or work), it is difficult to overcome the same criteria and standardized measurement and analysis methods for all types of ships. At the same time, it is difficult to model in the initial project phase, by numerical methods, the sources of noise and vibration [9, 11, 12, 18, 19].

On the other hand, due to lack of standards, there are difficulties in determining SPL (Sound Power Level) for large-scale noise sources such as the ship. Difficulties are caused by methods of measuring tonal components and directivity, as well as interaction and overlapping phenomena, especially at low frequencies.

Vibration and noise measurement methods are based on the following principles:
- Identify spaces from the ship with high values;
- Noise level;
- Frequency band;
- Periodicity of occurrence;
- Identification of sources;
- Analysis of working conditions;
- Analysis of the propagation medium (air, structure and water) [20].
Measurements are performed on a real-time ship with multi-channel systems with microphones, accelerometers or hydrophones, and a dedicated signal processing software. Measurements can also be made on a scale model [9, 11, 12, 18, 19].

The acoustic mobility of the engine foundation structure is determined by modal analysis, theoretical or experimental methods, or Statistical Energy Analysis [21].

The modeling of the signal transmission paths from the source through air, water and structure is done by using the near-field acoustical holography (NAH) method for modeling acoustic properties of the source by modeling radiation, diffraction and transmission between source and receiver through the vibro-acoustic transfer matrix [22, 23].

Although lately there have been many studies and research on noise generation, acoustic modeling of air and water propagation, and environmental management studies in this area, there is no global approach to vibration and airborne noise emissions in ships.

Noise and vibrations can be reduced by following the source-path transmission-receiver path.

A first way is to reduce noise and vibration at source.

The source isolation method is made from the design phase and constructive, each machine and equipment supplier must ensure isolation of the noise produced by the components or the moving agent.

The design of the propeller to eliminate or reduce cavitation is achieved by optimizing the propeller load, designing the optimal shape of the aft body for uniformity in the propeller disk, optimizing the propeller geometry by diameter, number of blades, pitch, skew angle, blade profile.

Another way is to isolate the source of the propagation medium (air, structure).

For structure, vibration reduction and thus noise propagation is achieved by increasing the structure's own frequency, which depends on the rigidity of the structure.

Last resort is the protection of the receiver.

Isolation of the receiver (space, ear protection of crew members) is a little expensive but does not solve the noise problem at the ship's level.

The use of the absorbent material generally does not alter the transmission of the noise from the source, but the reverberation time changes, creating a different sound image by diminishing the reflexive phenomenon.

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