MARITIME TRANSPORT VI

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6th INTERNATIONAL CONFERENCE ON MARITIME TRANSPORT

MARITIME TRANSPORT '14

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UNIVERSITAT POLITÈCNICA DE CATALUNYA
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PREFACE

Sea transport of goods and passengers is constantly undergoing a meaningful rise due to the globalisation of economy, thus provoking a trade speeding up and the specialization of ships and port terminals, with the support of the concept of comodality and its environmental face ecomodality.

Ports, are the decisive and needed node in the transport chain, must serve the maritime transport as an infrastructure providing a smooth change between modes of transport. These aspects shall be framed by the quality and environment-friendliness criteria that administrations and society require.

In this regard, protection of the port environment, safety and security have become key points for the development of modern maritime transport. In addition, the influence of human factor on board the ships has to be strongly considered as a decisive element for safe, secure and clean operations.

The MT'14 Conference is the last edition of a successful saga of congresses initiated in the year 2001 in its first edition, followed by further editions in 2003, 2006, 2009 and 2012. This event is an opportunity to meet researchers, scientists, academics, professionals, entrepreneurs, and all people involved in shipping and also in maritime training from any country. In its 2014 edition, administrations, institutions and companies will find a forum to meet, to exchange and to discuss their own achievements. With the back scenario offered by the Barcelona city and its enormous offer in touristical, cultural and gastronomic issues.

Welcome to the 6th International Congress on maritime Transport

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REVIEW OF LEGISLATION ON NOISE AND VIBRATION REGULATIONS IN MERCHANT SHIPS

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Abstract

This paper aims to describe the evolution of noise regulations for merchant ships over the last four decades, analysing the most important aspects with respect to crews, passengers and exposed populations in cities in line with the requirements of the European Union to reduce the environmental impact of transportation. The paper also analyses the changes in regulations aimed at not only regulating noise and vibration inside the ship, but also noise emitted to the port and underwater radiated noise.

We shall also include Classification Societies, given the importance of their standards in ensuring increasing levels of comfort on board ship.

Keywords

Noise, regulation, legislation

1. INTRODUCTION

Current strict specifications regarding the maximum levels of noise and vibration on board ship reflect the need for extremely careful planning from the early stages of ship design. This process involves detailed analysis of the different elements of the "sound circuit", identifying and characterizing the sources of noise on board, its receptors – situation and required limits– and the transmission paths linking the source with the receptors.

Two factors exist in the technological evolution of vessels that increase the problem of noise and vibration on board:

- a) The reduction in scantlings in the structures that form the vessel leading to increased flexibility and a reduction in the typical vibration frequencies of individual elements as well as of assemblies of such elements.

- b) Increased service speed and size respectively aimed at reducing transit time between ports and increasing capacity, which require the use of higher power propulsion engines and lead to increased rigidity in the shaft line.

To study noise and vibration on board ships, it is necessary to consider the sources of excitation as well as the structures that may be exposed to this excitation. Once the sources and affected structures are known, resonance phenomena may be studied to avoid excessive dynamic amplification. It is therefore advisable to maintain the different frequencies far from any foreseeable excitation frequencies.

Irrespective of the phenomenon of direct resonance between the sources of excitation and the structural elements of the assembly of the hull girder, some local structural assemblies may act as localized resonators capable of creating additional dynamic amplification of the stresses produced by the sources of excitation.

To further complicate the problem, the phenomenon of beats may cause resonance in structures whose actual frequencies are different from each of the excitation frequencies.

2. SOURCES OF NOISE ON SHIPS

The main sources of excitation, i.e. the primary sources of vibration (noise emission sources) in ships are: the propeller, the primary machinery, heating, ventilation and air conditioning (HVAC) systems, and exhaust gas systems.

There are also secondary sources of noise, such as: auxiliary machinery, hydraulic systems, different types of pumps, and the effects of the sea, wind, etc.

The propeller produces two types of excitation:

- *Alternative thrust*: giving rise to longitudinal vibrations in the shaft and machinery, which depends on the blade step-frequency - propeller revolutions multiplied by the number of blades ($\text{rpm} \times N$) -, and their harmonics.
- *Vertical pressure forces in propeller aperture*: causing vibration in the hull and superstructure induced by propeller cavitation.

Given the above, the propellers are often the main cause of the high noise levels that arise astern, and most of the low frequency noise in remote spaces, which spread to distant spaces via induced vibrations.

2.1. LOW SPEED MAIN DIESEL ENGINES (SLOW SPEED ENGINES)

Although there are vessels with diesel-electric engine propulsion systems and, to a lesser extent, steam turbines, most ships employ reciprocating internal combustion engines (slow speed diesel engines) as their propulsion system.

Two different types of forces may be associated with reciprocating internal combustion engines, namely:

Pressure forces due to combustion processes, and inertial forces. Both contribute to the vibration occurring in the engine structure. Their destructive potential lies in their

resonance with the lowest vibration modes of the hull reinforcements and the large second-order vertical moment.

In systems with several propulsion engines or multiple shaft lines, beats effects are likely to arise if the rotation speeds are not strictly equal. This phenomenon is intensified under poor weather conditions.

Table 1 - Average noise levels in dB(A) obtained experimentally.

Type of engine	Slow	Medium	Medium	Medium	Fast
		Group 1	Group 2	Group 3	
rpm	110-200	200-400	400-600	600-1.000	1.000-1.800
Maximum values	95-110	95-110	98-115	99-117	105-122
Average values	89-100	90-107	95-110	97-112	97-113
Control room values	69-80	70-80	74-80	80-86	87-88

Source [1]

The conclusion to be drawn from Table 1 is that noise emission is proportional to engine speed and that the values are above 95 dB(A). It may therefore be stated that the permissible continuous exposure limit is exceeded in all motor vessels in the engine room and that there is a need for a suitable control room.

Figure 1 - Types of noise emission generated by slow diesel engines on ships.

Source [2]

The primary sources of noise in two-stroke low speed propulsion engines are:

- The turbocharger
- Noise emitted by the exhaust valves
- Fuel injection systems
- The chain distribution system

The different types of noise emission generated by a diesel engine are the following: exhaust gas noise (due to gas pulsations), airborne noise (noise generated in the engine room) and structural noise (due to vibration in the engine bedplate).

2.2. VENTILATION AND AIR CONDITIONING

Forced ventilation and air conditioning systems are often the third major source of noise. This noise originates from:

- The fan itself and its motor.
- Air ducts and ventilation rates.
- Air entering the system due to suctioning.
- Air exiting the system through diffusers.

The noise in the ducts is due to two main factors: air speed and abrupt changes of direction in the elbows and intersections.

We shall now divide the ship into three main spaces in terms of noise measurement, namely:

- a) Noise in machinery spaces
- b) Noise in accommodation (cabins and public spaces)
- c) Noise in the wheelhouse

3. NOISE STANDARDS.

There is a need to differentiate between what is called health and safety on board and safety of life at sea.

Occupational health and safety on board falls within the scope of the prevention of occupational hazards. The legal scope of this occupational legislation is mainly the competence of national and EU authorities.

Regulations on Safety of Life at Sea are international in scope, while still forming part of Occupational Health and Safety.

3.1. INTERNATIONAL MARITIME ORGANIZATION (IMO)

To achieve its objectives, the IMO has adopted more than 40 Conventions and Protocols, which are binding legal instruments and, once put into force, their provisions must be implemented by all States that have signed them.

Once they have entered into force, the implementation of IMO conventions depends on the Governments of the States Parties.

In addition to conventions and other treaty instruments, the IMO also adopts many non-treaty instruments such as codes and recommendations. These codes and recommendations are not mandatory instruments; although Member States are expected to implement the provisions laid down in them, they are not required to do so.

There are currently over 800 codes, covering all areas of navigation. These include the Code on noise levels on board ships A.468 (XII) [3], adopted by the IMO in 1981. A new noise code is to come into effect in July of this year, via Resolution MSC 337. (91)[4].

The purpose of the Code is to limit noise levels and reduce worker exposure. The Code applies to new ships of a gross tonnage (GT) of 1,600 and above. The Code is not intended to be applied to passenger cabins or other passenger spaces, except insofar as such spaces are work areas, in which case they remain within the scope of the Code.

The provisions regarding potentially hazardous levels of noise contained in the Code shall also apply to existing ships with a gross tonnage of 1,600 and above insofar as this application is deemed reasonable and practicable to the satisfaction of the Administration.

The set noise level limits are designed to ensure that seafarers are not exposed to an L_{Aeq} (24) level above 80 dB(A), i.e. the exposure to equivalent continuous noise during a day or a 24-hour period is not to exceed 80 dB(A). In spaces where there are levels of acoustic pressure higher than 85 dB(A), it will be necessary to use suitable hearing protection or apply exposure time limits as provided for in this section to ensure an equivalent degree of protection.

3.2. NEW IMO REGULATION MSC 337. (91).

Seeing as the previous regulation dated from 1981, in October 2007 the Maritime Safety Committee (MSC) decided to revise the code (MSC83). The revision was completed in November 2012 and its amendment shall enter into effect in July 2014.

The revised noise limits distinguish between two ship sizes:

- 1,600 up to 10,000 GT
- 10,000 GT and above

From the table 2, it can be seen that the recommended noise levels are maintained with two exceptions: non-specified work spaces, in which the maximum noise levels are reduced by 5 dB, and in machinery spaces (in which the distinction between

permanently manned or not permanently manned spaces has been removed), representing an increase of 20 dB . This is seriously harmful for engine room staff.

Table 2 - Noise level limits in bridge and machinery spaces. Sources: [3] and [4]

<i>Designation of rooms and spaces</i>	New Code		Current Code
	1,600 up to 10,000 GT	≥10,000 GT	
<u><i>Work spaces (in dB(A))</i></u>			
<i>Machinery spaces (permanently manned)</i>			90
<i>Machinery spaces (not permanently manned)</i>			110
<i>Machinery spaces</i>	110	110	
<i>Machinery control rooms</i>	75	75	75
<i>Workshops</i>	85	85	85
<i>Non-specified work spaces</i>	85	85	90
<i>Designation of rooms and spaces</i>	New Code		Current Code
	1,600 up to 10,000 GT	≥10,000 GT	
<u><i>Navigation spaces (in dB(A))</i></u>			
<i>Navigating bridge and chartrooms</i>	65	65	65
<i>Look-out posts (incl. navigating bridge wings and windows)</i>	70	70	70

Source [2]

The limits have not been modified in navigation spaces, ranging from 60 dB in radio rooms and 70 dB in navigating bridge wings. Hence, the auditory stress suffered by bridge and radio staff is much lower than that suffered by engine room staff. The remaining spaces continue to have the current noise level limit.

There is an improvement in the limit in the accommodation spaces of vessels of 10,000 GT and above, being reduced by 5 dB compared to the levels of the current code, except in recreation rooms, where the level is maintained at 75 dB. This measure seems correct in our opinion, although we understand that it should also apply to vessels of below 10,000 GT.

Table 2 - Noise level limits in bridge and machinery spaces.

<i>Designation of rooms and spaces</i>	New Code		Current Code
	1,600 up to 10,000 GT	≥10,000 GT	
<u><i>Accommodation spaces (in dB(A))</i></u>			
<i>Cabins and hospitals</i>	60	55	60
<i>Messrooms</i>	65	60	65
<i>Recreation rooms</i>	65	60	65
<i>Open recreation areas</i>	75	75	75
<i>Offices</i>	65	60	65

Sources: [3] and [4]

The new code will, in general, be mandatory, though some parts will not: for instance, those parts referring to existing vessels of 1,600 GT and above, and new ships of below 1,600 GT, operating conditions in port, noise exposure limits, insulation materials and the selection and use of hearing protectors, in addition to all the appendices except for the first one.

The new code establishes that a noise survey report is to be made for each ship and that this report is always to be carried on board.

3.3. NATIONAL REGULATIONS

The one currently in force is R.D. 286/06 [5]. Although the latter also initially excluded on-board staff, the Transitional Provision establishes that it is to be applied to these workers from November 2011. Although this legislation is better than nothing, it only makes reference to daily noise exposure limits. The values are quite consistent with IMO regulations.

3.4. CLASSIFICATION SOCIETY REGULATIONS ON NOISE

In addition to international standards and national regulations, Classification Societies have included in their Regulations, a notation aimed at assessing comfort (the COMF notation) with respect to noise and vibration on board, making on-board comfort more realistic. Ship-owners and shipyards find it convenient to use the standards of classification societies as a set of objective criteria on which to base the shipbuilding contract.

The following Noise Standards are frequently used by Classification Societies:

IMO Res. A. 468 (XII) - "Code on noise levels on board ships.

ISO 2923, "Acoustics - Measurements of noise on board vessels.

ISO 140, in particular Part 4 (Field measurements of airborne sound insulation between rooms) and Part 7 (Field measurements of impact sound insulation of floors).

ISO 717, in particular Parts 1 (Airborne sound insulation in buildings and interior elements) and 2 (Impact sound insulation).

Of the ten companies that are members of IACS (International Association of Classification Societies), the most important worldwide are: American Bureau of Shipping (ABS), Bureau Veritas (BV), Det Norske Veritas (DNV), Germanischer Lloyd (GL), Lloyd's Register (LR) and Registro Italiano Navale (RINA).

These Societies provide 3 grades for evaluating comfort in relation to vibration (except the GL, which provides 5 and the ABS, which provides 2). Grade 1 is the best comfort and Grade 3 the worst, with the lowest level of comfort.

The required levels of noise are very similar in all Classification Societies, small differences existing between the requirements for passenger cabins (first class or standard) and outdoor facilities. These may be summarized as follows:

- Passenger cabin (first class): 45/47/50 dB(A) (Grade 1-3)
- Standard cabin: 50/53/56 dB(A)
- Exterior Facilities: 65/70/75 dB(A)

Table 4 - Summary of the "Comfort Class" range of requirements regarding noise of different Classification Societies. Minimum column: most restrictive requirement (Grade 1). Maximum column: least restrictive requirement (Grade 3).

Type of space	Noise limit dB(A)	
	Minimum	Maximum
First class passenger cabins	44	56
Standard passenger cabins	45	60
Crew cabins	50	60
Wheelhouse	55	65
Engine room	108	110
Unmanned machinery spaces	85	90
Engine control room	69	80
Workshops	82	85

Source: [16].

The location of the points of measurements and tolerances are the criteria that differ the most from one Society to another. The majority of Societies employ tolerances, although they differ with respect to their criteria. Some Society allows exceeding a percentage of maximum levels (BV, DNV, RINA), for others, excessive levels lead to new measurements (LR) while no tolerance is supported in other cases (ABS, GL).

While Classification Society requirements regarding vibration vary considerably (although they are lower than the ISO standard, which sets an upper limit of 9 mm/s) [17], there is substantial consensus on noise requirements.

3.5. EUROPEAN DIRECTIVES ON NOISE

Through its "Green Policy", the European Union has imposed increasingly stringent requirements to reduce the environmental impact of all types of transportation. This has been accompanied by the emergence of new Directives.

These requirements are presented in three areas:

- Noise and vibration on board ships
- Noise radiated from ships in ports
- Underwater radiated noise

We shall now briefly enumerate the regulations regarding the last two groups, as that relating to the first group has been analysed in the preceding sections.

3.5.1. SPECIFIC REGULATIONS FOR THE CONTROL OF NOISE RADIATED FROM SHIPS TO THE PORT AND INHABITED AREAS IN INLAND WATERWAYS

- 2001 - EN ISO 2922:2000 [18]. This standard specifies the conditions for the measurement of airborne noise emitted by vessels of all types on inland waterways and harbours, except for powered recreational craft, as these are regulated by ISO 14509. It is applicable to small offshore vessels, harbour craft, dredgers and all those watercraft, including those that are berthed, used as or with the capacity to be used as a means of water transport.
- 2002 - Directive 2002/49/EC [19]. This Directive has the following aims:
 - To establish a common approach intended to avoid, prevent or reduce on a prioritised basis the harmful effects, including annoyance, due to exposure to environmental noise.
 - To provide a basis for developing EU measures to reduce noise emitted by major sources, in particular and rail and road vehicles and infrastructure, aircraft, outdoor and industrial equipment and mobile machinery.
- 2006 - Directive 2006/87/EC. The noise generated by a vessel under way shall not exceed 75 dB(A) at a lateral distance of 25 m from the ship's side and the noise generated by a stationary vessel shall not exceed 65 dB(A) at a lateral distance of 25 m from the ship's side, apart from transshipment operations.

- 2007 - EN ISO 14509-2:2007. This specifies procedures for assessing the maximum noise emitted by powered mono-hull recreational craft of up to 24 metres in length.
- 2009 - EN ISO 14509-1:2009. This standard evaluates emitted noise using calculation and measurement procedures.

A ship is a complex source of radiated airborne noise. The ship's internal sources of structural noise can induce vibration in the hull, thus becoming generators of airborne noise. This mechanism is considered negligible and is not considered in the noise emitted to the outside.

However, the sources of airborne noise to be taken into consideration are those which, despite being located inside the ship, are in communication with the outside through openings such as funnels, where exhaust gases are emitted to the atmosphere, and the suctioning and discharge of heating, ventilation and air conditioning (HVAC) systems.

These simple sources are distributed throughout the ship both lengthwise and vertically, generating a complex 3D field of radiated noise from the ship.

Moreover, different operating modes can be identified for the ship, each characterized by different on board sources and/or making different contributions to the total radiated noise:

- a) Ship navigating along the coast. The most important source is represented by the propulsion engine and the discharge of exhaust gases.
- b) Ship manoeuvring (entering/leaving the harbour). Here the main engines are operating outside of nominal design conditions and other manoeuvring equipment is operational (lateral bow or stern thrusters, auxiliary azimuth thrusters, cargo winches, capstans, etc.).
- c) Ship at the dock (no loading processes)
- d) Ship being loaded and unloaded. In these last two cases, it is assumed that the main engines are not running, while the auxiliary engines are. This case is characterized by specific component noise due to the operation of cranes, ramps and other means of loading and unloading (which can produce noise of an impulsive nature).

3.5.2. REGULATIONS AND STANDARDS PERTAINING TO SHIP UNDERWATER RADIATED NOISE

The main source of underwater radiated noise is obviously the propeller, as well as the propulsion machinery due to inducing structural vibration.

Other features that influence the emission pattern and intensity of the radiated noise are:

The directivity of the sound, the dimensions of the vessel and its speed (the faster the speed, the higher the emissions), load conditions (higher emission levels when the ship is in ballast condition), type of propeller (controllable pitch propellers are the most problematic) and vessel maintenance.

The receptors of this noise are marine wildlife in general, although marine mammals are affected the most, as they rely on sound to communicate, coordinate their movements, navigate, explore the environment, find food and avoid predators.

The absence of environmental requirements regarding ship underwater radiated noise has been widespread in almost all contractual specifications until now, with the exception of the most modern oceanographic and fisheries research ships.

The emergence of international, national and regional associations for the protection of marine mammals has led to the drawing up of a series of regulations that address underwater radiated noise and its potentially adverse effect on marine life. Noteworthy in this respect is the International Council for the Exploration of the Sea (ICES), whose Requirement 209 [24] sets a limit to the level of lateral noise radiated underwater by the vessel at 1 m from the ship's side. By means of the ICES methodology, it has been found that the noise radiated by the ship hull at 1 metre from the hull should not exceed 132 dB [20].

Directive 2008/56/EC [21] comprises an international legal instrument which includes human-induced underwater noise in the definition of pollution. The Acoustical Society of America (ASA-URN) has published a Procedure for Measuring underwater radiated noise.

In 2010, the DNV Classification Society issued the Silent Class Notation [22], setting different limits for each type of vessel. This notation includes procedures for measuring underwater radiated noise.

It can be seen that regulations are being drawn up to define the requirements for new construction ships which will include limits for different aspects of the total acoustic signature (Noise and Vibration Full Signature) of each vessel: noise and vibration on board, noise radiated to the port and underwater radiated noise.

3.6. EUROPEAN PROJECTS ON NOISE (Related to Directive 2002/49/EC)

Ecoports

Research projects focused on the development and implementation of tools to improve the environmental characteristics of ports. This project includes NoMEPorts

NoMEPorts

Its main objective is the reduction of noise related to health problems and annoyance caused to citizens living near industrial port areas using noise maps (with the help of specialized software for predicting noise) and a noise management system to be used specifically in industrial port areas.

The noise sources related to traffic in port areas are the roads, railway infrastructure and air traffic. Examples of sources of industrial noise in port areas are the port facilities, terminals, cargo handling and storage terminals, industrial sites, machinery and workshops, ships under construction, repair and maintenance, slipways and moored ships (engine noise).

The project has carried out an analysis of the characterization of the different sources of noise in a port which has shown that the contribution of ships to ambient noise is primarily due to the operation of internal combustion engines.

Harmonoise/Imagine

These projects have developed a methodology for modelling various types of noise sources. The Harmonoise project focusses its efforts on noise prediction methods for roads and railways, while the scope of the Imagine project extends to the sources of aircraft and industrial noise. It considers only industrial sources, because the noise emitted by ships is included in this source category.

SIMPYC

The objectives of this project include finding solutions to certain problems arising in relations between the port and the city aimed at establishing a friendlier environment and a functional relationship model, while developing coordination between port activities and the city.

These problems are basically: noise pollution, air pollution and environmental impact.

HADA

This project is a tool designed to establish a methodology to control noise levels in Spanish seaports.

Table 5 - Summarized inventory of sources of noise around port areas .

Inventory of sources of noise around port areas	
Priority level	List of activities and sources of noise
High	Scrap iron (unloading of the ship at the dock and loading from the dock to the truck)
	Iron and steel products
	Containers
	Repairs
	Shipbuilding
	Heavy traffic
Medium	Railway noise
	Port warehouses (depending on the type of goods)
	General merchandise (non-ferrous metals, wood, paper, plaster, etc.)

	Dockage of Ro-Ro vessels
Low	Liquid cargo without special facilities
	Solid cargo without special facilities
	Petroleum products due to their special facilities
	Fishing: sale, ice plant, refrigerators, etc.
	Passenger ships: ferries, cruise ships

Source: HADA Project

As in most ports, the main sources of noise are the movement of metallic parts, road haulage traffic and trains. Ships constitute a medium-low source of noise impact, with the exception of the noise emitted during loading and unloading operations.

SILENV project [23]

Among other objectives, this project aims to assess methodologies and criteria for the analysis of the noise ships emit to the outside. One of its goals is to model the propagation of airborne noise to the outside for various types of vessels.

In general, strategic noise maps are obtained by superimposing the calculated sound fields for each source (ships and other possible contributions). The ultimate goal is to assess the noise levels produced in receptors (population exposed to noise), i.e. the population living near the port.

AQUO Project

The aim of this project is to assess and reduce the underwater acoustic impact from maritime traffic using tools to detect, predict and reduce ship radiated noise.

4. ANALYSIS OF NOISE LEVELS IN DIFFERENT TYPES OF SHIPS

In the preceding paragraphs, we have seen that ships are mobile industrial noise-generating facilities as a result of the multitude of machinery on board, their propulsion systems, the systems for the comfort of the crew and passengers and operating requirements and conditions. Noise generated on board affects crews. Noise radiated in port affects the people living near port areas. Underwater radiated noise affects marine life.

Table 6 - This table summarizes the evolution of noise regulations on ships

	Noise on board (inside the ship)	Radiated noise in ports	Underwater radiated noise
1974	SOLAS (Protection against noise)		
1975	IMO A.343 (XII)		

1981	IMO A.468 (XII)			
1984				
1990s	Comfort Class Notations			
2000				
2001		ISO 2922:2000	International Union for Conservation of Nature RESWCC3-0638	
2002		Directive 2002/49/EC		
2003	Directive 2003/10/EC ILO Maritime Labour Convention			
2006	Directive 2006/87/EC ILO Convention No. 188 (Fisheries sector) ILO Recommendation WFS		ICES No. 209	
2007	Review IMO A.468 (XII) (85 dB(A) – 80 dB(A))	ISO 14509-2:2007		
2008			Directive 2008/56/EC	
2009		ISO 14509-1:2009	Silent Class	
2010				
2012	MSC 337(91)			

Source [12]

Table 6 provides a summary of noise regulations in three areas. IT can be seen that regulations on noise on board ships have been developed further than those on radiated noise in ports and underwater radiated noise, as the awareness of noise pollution from means of transport reached a highpoint in the last decade.

After nearly four decades of developing regulations regarding shipboard noise, it is our opinion that the hearing health of seafarers is still not adequately protected. Nonetheless, ships classified by companies belonging to IACS are in a better situation because of the higher technical requirements of this organization, which include not only limits to noise and vibration levels, but also sound insulation and impact sound

limits. The additional requirements on noise emitted to the outside set by the European Union will favour the reduction in noise on board, and *vice versa*.

A review of noise levels on board ships measured by different agencies and researchers over the years reveals the following values:

- a) Nilsson [6], measured existing levels in 282 cabins on 15 vessels chosen at random, finding the distribution shown in the following figure:

Figure 2 - Histogram distribution of noise in 282 cabins on 15 different ships.

Source [6]

As can be seen, the recommended level of 60 dB(A) is exceeded in two thirds of the cabins.

- b) Szuwarzynski et al. [7] studied the distribution of noise in 1,360 cabins on 45 merchant ships, finding that the limit of 60 dB(A) is exceeded in only thirty percent of these, as shown in the following figure.

Figure 3 - Histogram distribution of noise in 1,360 cabins on 45 different ships.

Source [7]

c) Experimental levels in bulk carriers [8]

The table presented below was obtained by measuring noise levels in fourteen ships of the same size and type (bulk carriers), built in the same shipyard, with the same propulsion engine, machinery and accommodation aft, in the same ballast condition during speed trials and with the engine operating at maximum rpm. Average values are presented:

Table 7 - Average noise levels in dB(A) of a group of 14 bulk carriers

	NF	dB(A)	SIL
Workshop	94	98	91
Galley (with extractor fan)	82	84	77
Galley (without extractor fan)	69	74	68
Cabin (main deck)	65	67	55
Cabin (lower deck)	57	61	50
Cabin (officers' deck)	56	61	47
Cabin (bridge deck)	54	59	49
Control Room	75	79	71
Wheelhouse	-	68	-
Engine (top)	98	103	96

Source [8]

Engine Room

The average noise level in the Engine Room is 104 dB(A), so it is essential to have an Engine Control Room. The average value in these is 79 dB(A), which exceeds the recommended level of 75 dB(A).

Outside the control room, average values of 103 dB(A) are obtained at the top of the engine, so it is not possible to hold a conversation here without shouting.

The recommended level in the Engine Room workshop is 85 dB(A), while the measured value is 98 dB(A) and hence too high. Understanding what is said here is hence very difficult.

Wheelhouse

The average level is 68 dB(A), while the recommended limits are 65 dB(A).

It can be seen that the limits are generally exceeded in almost all spaces on board.

a) Experimental levels of noise on tankers [9]

Buiten obtained the results discussed below from an experimental study of existing noise and vibration on eleven tankers ranging in size from 18,000 to 200,000 GRT.

The results for two representative types of vessels are summarized below: one of 200,000 GRT sailing at full load, and another of 70,000 GRT in ballast.

On the 200,000 GRT vessel, a large difference in the noise level was registered between the Engine Room (105 dB) and Accommodation (68 dB), this difference increasing with increasing frequency (greater difference at higher frequencies). A significant low frequency component existed in the crew cabins, dropping to 23 dB in the 31.5 to 250 Hz frequency range. A peak appears at 500 Hz which raises the noise figure (NF) to 67, practically coinciding with the sound pressure level of 68 dB(A). Third octave band frequency analysis of the noise and vibration on board reveals dominant frequencies. A peak appears at 5 Hz attributable to the propeller, which was rotating at 5.4 Hz at the time of measurement. At frequencies between 10 and 63 Hz, a band of relatively constant noise was observed that was attributed to structural transmission of the engine noise which is partly radiated through the air to the cabin.

As for the 70,000 GRT vessel, the characteristic peak of propeller noise is clearly observed at a frequency of around 8 Hz, the propeller rotating at 7.9 Hz at the time of measurement. The bridge crew was subjected to an equivalent continuous sound level of 66 dB(A), and to 71 dB (A) in the mess and 68 dB(A) in their cabins. Similar values were found for the rest of the deck crew.

b) Summary of noise levels for various types and sizes of vessels [10]

The following table is a summary, from the DNV Classification Society, of average noise levels in dB(A) for different types and sizes of vessels

Table 8 - Noise levels on different types of vessels.

Tipos de buque		Grupo de buque	Sala de máquinas	Cámara de control	Camarotes						Puente de gobierno	Alerones del puente	Áreas de recreo al aire libre
					Bajo superestructura		En superestructura						
2	1	A	B	C	D								
Superestructura a popa	Petrolero	A ₁ (turb)	95- 100	69	-	65	57	54	50	48	56	65	70
	Granelero	A ₂ . > 50000 tpm	96- 108	72	-	66	60	57	54	51	59	69	70
	OBO	A ₃ .10-50000 tpm	100- 110	73	-	67	62	59	56	53	61	71	75
	LPG/ LNG	A ₄ . 5- 10000 tpm	103- 110	76	-	69	64	61	58	55	63	73	75
	Carga general	A ₅ . 1- 5000 tpm	103- 110	80	-	71	66	63	60	-	65	75	80
	Portacontenedores	A ₆ . < 1000 tpm	105- 110	-	-	75	70	67	-	-	69	79	-
Superestructura a ¼ partes de la popa	Frigorífico Portacontenedores	B	100- 110	75	-	67	60	57	55	53	60	70	75
Superestructura a proa	Ro- ro	C	105-110	78	-	60	55	52	49	47	57	65	70
	Portacontenedores												
	Carga general	D											
	Offshore												
	Remolcadores	Tránsito	107- 112	80	62	61	58	55	-	-	63	79	-
	Maniobra		107- 112	80	81	75	69	63	-	-	66	79	-
	Pasajeros/ Cruceros/ Ferries		105- 110	75	75/ 45	71/ 43	66/ 48	62/ 43	56/ 42	54/ 39	55	65	70

Source: DNV

From the above table, it can be seen that the higher the deck is with respect to the engine room, the lower the level of noise. Nevertheless, in almost no case does it exceed 65 dB(A) (except in vessels of less than 1000 dwt), when the cabin is located above the superstructure. This value is exceeded, however, when the cabin is located below the superstructure. The values recommended by the IMO are 60 dB(A) for smaller vessels and 55 dB(A) for larger vessels. These limits are met in cargo ships from deck B (second deck starting from the main deck). The vessels that most fail to meet the recommendation are small container ships. Clearly, the sound insulation of cabins located on the main deck, and those below it needs to be improved, or accommodation should be located exclusively from the lower deck with respect to the main one.

As for the noise levels of the wheelhouse, the limit recommended by the IMO of 65 dB(A) is once again not met by tugs when manoeuvring or in small container ships. In general, there seems to be no problem in these spaces.

The value recommended by the IMO for the engine control room is 75 dB(A), which is not met in low tonnage ships, such as tugs, general cargo vessels of below 5,000 dwt or Ro-Ro vessels. This may be because there is no control room separated from the machinery spaces on the majority of these small tonnage vessels.

Finally, the noise levels in the engine room exceed 100 and even 105 dB(A) in almost all vessels. The only vessels found within a range whose lower limit is below 100 dB (A) are those powered by turbines (currently a very small number of vessels with respect to the world fleet) and bulk carriers of 50,000 dwt and above.

c) Tables summarizing noise data on Ro-Pax vessels [11] (data from LAV, Cadiz)

Measurements made by the Acoustics Laboratory (Spanish acronym, LAV), University of Cádiz, were primarily used to prepare the following tables.

Table 9 - Summary with maximum noise levels in different spaces, in all constructions.

	Ro - Pax Vessels (<200 m)				
	78/79	80	81	86	Juan J. Sister
Engine Room	105	105	105	110	109
Engine Control Room	85	70	68	74	71
Wheelhouse	64	65	61	61	54
Cabins	61	55	53	70	59
Recreation areas	--	61	60	71	79
Workspaces	86	85	84	90	92

Source: [12]

Most of the standards referred to in this paper consider only sound pressure levels, without any additional parameter (noise spectrum, low frequency components, tonal or impulsive components, reverberation), which may reduce or increase discomfort due to noise, although criteria do exist in this respect, such as RC Mark II [13], used by ASHRAE [14] for interior spaces. Neither do the standards take into account indicators on the intelligibility of communications, such as the SIL index [15].

By requiring shipyards to make a predictive calculation of noise in the design phase of new construction ships. Furthermore, this Code requires the drawing up of a final noise report, which must be deemed satisfactory before delivery of the vessel to the ship-owner. In our opinion, noise levels on board should be checked on a periodic basis, and not just on completion of construction.

The new regulatory requirements being introduced by the European Union on noise radiated to the outside and underwater radiated noise will also make noise and vibration critical in the design of new ships. This will constitute a niche market for shipyards that take these requirements into account and will suppose a challenge for shipbuilding in Spain, which will need to adapt its processes so as to meet standards imposed at a global level to reduce noise pollution.

IMO requirements concerning the use and instruction to use hearing protection could be included among the operational procedures of the ISM Code for the Safe Operation of Ships, leading to increased awareness on the part of crews and effective control on the part of maritime agencies when performing audits.

Methodologies have been developed for the successful implementation of the necessary measures to characterize vessels acoustically. Furthermore, sound pressure limit levels have been investigated with the aim of protecting the health of the population exposed to this form of noise.

Projects promoted by the EU aim to reconcile three environmental issues: energy efficiency, gas emissions and noise emissions. The ultimate goal is to reduce noise

pollution on board and in port, minimizing the number of people exposed to undesired levels of noise.

5. CONCLUSIONS

We highlight the differences that exist with respect to workers on land, especially during periods of rest.

From the data on noise levels in Section 4, it can be seen that:

- The level of noise in the different workspaces on merchant ships routinely exceeds recommended levels in the governing regulations. We believe this is why the Classification Societies permit tolerances in compliance percentages.
- The requirements of Classification Societies are more demanding in general (except with respect to Grade 3) than IMO requirements (which we understand as minimum targets). Thus, if the average level measured on board is close to the IMO limit, the noise level may be considered "improvable", while if the average level is 5 dB or more below this value, the noise level may be considered "acceptable". Obviously, values exceeding these limits are totally unacceptable and corrective measures must be taken.
- The places on the vessel where these recommended levels are systematically exceeded (for almost all different types of vessels) are machinery spaces. This is compounded when considering that the IMO has set a level of 110 dB(A) from 2014 on for all machinery spaces (as there is no distinction, as in the previous regulations, between manned or unmanned spaces).
- This amendment to the regulations for machinery spaces will make the existence of a control room in new construction ships of 1,600 GT and above mandatory to avoid exceeding the level of 80 dB(A) of daily exposure to noise, given the high power vessels employ in confined spaces and the fact that noise spreads more easily through the hull and steel structure, which have a higher acoustic impedance.
- The most effective measure for reducing the level of noise in the engine room is to install quieter engines (whenever possible, different types of propulsion engine to the reciprocating internal combustion engine). Other possible alternatives are: to improve the absorption from noise of the engine room (to reduce reverberation), mounting the noisiest engines on elastic suspension mounts, and improved isolation of the control room so as to achieve levels of intelligibility in communications and hence greater safety in the operation of the vessel.
- As for corrective measures and suggestions for improvements on deck, these should focus on improving the layout of the superstructure (as accommodation both for the crew and passengers is usually located in these spaces) and sound insulation of the cabins via the installation of floating floors, sound-absorbing walls and ceilings, and placing accommodation as far as possible, both horizontally and vertically, from machinery spaces. In view of the results, a very effective measure on vessels with reduced accommodation (generally, cargo ships) is to place the cabin from lower deck.

- These standards and recommendations do not pay due attention to vibration (closely related to noise) or to the frequency spectrum to determine whether there are tonal components, low frequency noise or impulse noise, setting only the maximum overall equivalent continuous levels in dB(A) and, in some cases, the noise feature (NF). In our opinion, therefore, other criteria, such as RC Mark II, should be employed so as to take into account the subjective degree of discomfort for people due to noise, in addition to its level.
- Noise problem to seafarers (especially engine room crew) are an undoubtable fact, as noise levels in these spaces exceed 100 dB(A), as we have seen in previous sections. Besides the aggravating circumstance that Spanish legislation on the protection of workers from risks related to exposure to noise excluded seafarers from its scope of application until November 2011 (Transitional Provision of Royal Decree 286/06).
- The fundamental problem of noise on board ships is mainly located in machinery spaces, where the use of hearing protection is essential. Actual levels in other spaces are not as critical. However, with the use of current techniques for reducing noise and vibration, collaboration between shipyards, ship-owners, suppliers of equipment and technical experts from the Classification Societies and the use of vibration and noise prediction to detect conflictive points and propose improvements, optimal levels of quality in comfort and habitability may feasibly be achieved on board ships.

The European Union and North America are working along these lines, while other countries should follow the path already travelled in these fields and the regulations that have respectively been developed in their regard.

In line with the results obtained in the SILENV project [23]), we may state that:

- Strict compliance with IMO (noise) and ISO (vibration) requirements on the ships making up the current fleet (regardless of the compliance of some vessels in particular) is not achievable in the short to medium term.
- Attempts to apply more stringent limits than current standards to the existing fleet will entail higher percentages of incompliance, given that the European merchant fleet does not generally comply with this new environmental regulatory framework. This will dictate corrective policies.

Possible strategies to improve the situation include:

- Specific policy actions to reduce the environmental impact of ships.
- A gradual renewal of the fleet is more feasible, given that the average age of the fleet means that modifications to improve the environmental impact of its vessels is not economically viable and the technical execution of such measures is likewise problematic.
- Any project promoted by the EU should reconcile three environmental issues: energy efficiency, gas emissions and noise emissions.

Thanks to the policies that are being developed within the European Union, the improvement in radiated noise in port and underwater radiated noise will also be

accompanied by an improvement in the noise level inside the vessel, and *vice versa*. The ultimate goal is to reduce noise pollution on board and in port, minimizing the number of people exposed to undesired levels of noise.

The EU's regulatory framework for noise and vibration needs to be further developed to achieve lower levels of noise and vibration emitted by ships both at sea and in port, integrating ports into their cities via proper planning that may be accomplished with the help of strategic noise maps.

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