Noise & vibration control on board of luxury passenger ships

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Abstract
The issue of comfort on board of passenger ships has became in the last years of paramount importance; in this context the noise and vibrations control plays the leading role specifications. The report analyses also one of the most important component of disturbance, that is to say the noise in the accomodation areas due to the entertainements noise. Sound on board is needed for passenger's entertainement purposes; but while the physics of sound is the same of sound on earth, the problems that can arise are different due to the steel structure of the ship. Another frontier for the shipbuilders is represented by the acoustic pollution that concerns the ship external environment and therefore the control of noise spread in the air and in water

INTRODUCTION

In order to understand the technological process that is taking place today in shipbuilding, following upon the demand for continuous innovation, the global progress made over the last few years in the other transportation sectors should be analysed.
With regard to comfort, the progress made in this field is such that every one of us feels “uncomfortable” under conditions that until very recently were considered “normal”on board of a ship.
Hence the Shipping Companies demand for ever stricter limits for vibration and noise, failing which the economic consequences might be very serious. This explains the need for Shipyard to cope with the ensuring problems with suitable instruments, from the design to the delivery of the ships.
In the last years, the world demand of passenger ships has registered a constant increase and in this market the European shipyards have played and are still playing a fundamental role.
In view of the strong competition among the different European shipyards, triggered by the shipowner’s demand ever more keen to the quality of the product, the ability to offer a ship featuring a high level of comfort represents a decisive factor for the success of a design.
The paper its divided in three parts: the first regards the classical and traditional approach to study the vibration and noise problems in the ships, the second deals with the most important problem that nowadays regards the cruise ship - that is the comfort - and the third and last parts discusses the most important problems in the future: acoustic pollution that concerns the external environment and therefore the control of noise spread in the air and in the water.

CLASSICAL APPROACH

Hull and local vibrations

In the areas of control of hull vibrations, Fincantieri began to with know-how acquired through their experience of merchant vessels. This experience indicated that certain types of vessel (Ro-Ro,container's ship and others)run a high risk of superstructure vibration.
For these type of vessels, Fincantieri have chosen to develop their own propeller design, as the propeller are the main excitation source, to design their own hull structures and make their own provisional vibration calculation
The same principles are applied to Cruise ship, except that the actual propeller design work is made by some subcontractors.
In the cruise ships, the optimization of the main parameters of the vessel's dynamic behaviour-hull line, wake, propeller thrust and excitation, on one hand, and of hull structure geometry and scantlings, on the other-has obviously benefited from the experience recently acquired by Fincantieri in the other passenger ships.

Dynamic calculation procedure

The structural models obtained by means of the Finite-Element method are such that both static and dynamic calculations can be made, with the minimum adjustement and integrations that may be necessary.
The propeller design procedure entails the computation of surfaces forces induced by the blades on the vessel's stern, and the forces and the torques acting on the propeller shafts. Since the computation takes into consideration the blade and the hull shapes and the hull wake as measured in the tank model tests, the optimizing procedure provides for a reduction in the excitations, insofar as the propeller hydrodynamics performances are not excessively penalized.
For the ships, the computation is supported by experimental tests, by hull model tank tests, to achieve the most even possible wake in the propeller area, and by propulsion propeller model vacuum tank tests to obtain experimental data on the propeller thrust and excitation pressures. The experimental data are introduced in the vibration calculations.
Such method fosters the designer's special "sensitiveness" in the detection of the structural elements that characterize locally the dynamic behaviour of the ships at the various frequencies.
A general suggestion provided by these calculations can be the opportunity to increase same structural elements of the stern areas in order to quieten the public spaces of the upper decks.

Vibration Measurements on Board

Fincantieri "noise and vibration office" is so organized that the people who make theoretical hull vibration calculations is the same that perform vibration measurements on board; in this way this people is the most right to judge the job made with all the connected technical aspects.

The difficulty of relating computed amplitudes to those detected on board must be taken into account, a careful analysis of the dynamic calculation at the provisional stage can be correctly identify critical frequencies and the structural components responsible for the dynamic behaviour of the hull, thus allowing designers to improve so as to optimize the final dynamic performance.

Noise Control

Since the proper development of the general plant of the ship has a major bearing on the final acoustic results, noise control starts already at the preliminary stage of the design definition, trying to remove the critical situation from the outset. With the gradual development of the design and the beginning of the building activity, noise control interacts all the more with most of the other activities and the consequent contrasting requirements are to be reconcilied, whilst keeping costs to the minimum and achieving the results.

During the development of the design the main plants of the ship are worked out.The noise control staff defines, by means of data banks and often in co-operation with the supplier, the admissible levels of airborne and structuralborne, noise that the plant itself can transmit on board to the ship.This stage is of special importance because it involves major technical and economic aspects, with repercussions on the purchase policy, and fixes the target values of the excitation sources on board.

Once the ship design is sufficiently defined and the contract with shipping company is signed, all the main elements are known to perform in details the forecast calculation on board. In this way usuful informations can be rapidly obtained to detect the critical aspects of noise on board, with regard to the basic configuration of plant engineering in order to make timely adjustement where necessary.

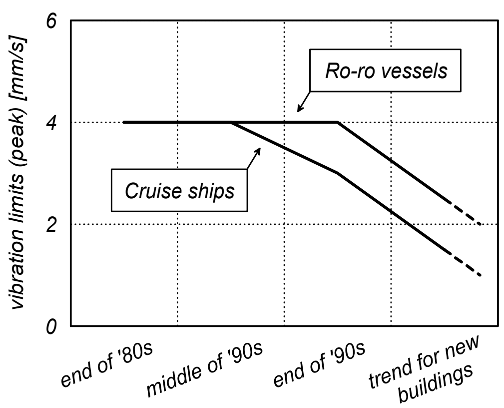
PROBLEM OF COMFORT

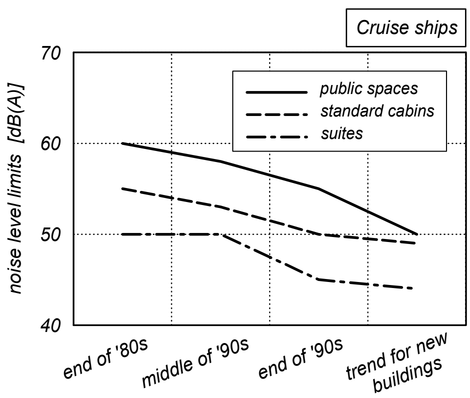
The comfort on board a ship expresses the condition of well-being perceived by the persons staying on board and is hardly classifiable with formulas, numbers and limits. The conditions that determine the levels of comfort are, in fact, rather complex since they are the product of both a subjective and an objective component.

To better explain this aspect of the comfort that may seem obscure, let’s take into consideration for instance the case of a cabin that, under equal cruising conditions, has been the subject of a claim (that is to say, has proved “not comfortable”) only for one voyage. Probably, its habitability was actually satisfactory and the claim was presented by a passenger with subjective demands of comfort higher or simply different from the average requirements.

This means that it is not possible to guarantee a sensation of comfort equally valid for everybody. For this reason, the designer must aim at securing a “suitable” comfort level and this can be attained taking advantage of the experience acquired on similar ships, bearing in mind the suggestions of the shipowner who can directly weight the actual habitability conditions of the ship and can therefore update the designer.

On one side, the fact that the claim is occasional is not a sound proof of a lack of comfort and consequently the design solutions adopted against noise and vibrations remain valid. On the other side, the repeatability of claims concerning the same cabin and presented, under the same cruise conditions, during different voyages, may be considered the proof of a low level of comfort.
Actually, it may well happen that, for instance, even if the noise background levels are low during normal operating conditions of the ship, there occur “disturbances” that affect the sensation of comfort in the cabin. Such disturbances may be caused by intermittent fortuitous noise or by noise caused by the entertainment system.
The reduction of comfort may however have some other source. In fact, it may happen that the background noise does not have a spectrum evenly flat: in other words, it may happen that a cabin be not comfortable because, notwithstanding the low air noise level measured, there is a tonal component prevailing on the others.
Concerning the noise, therefore, it means that there is not a close correlation between the decreasing level of sound pressure in dB(A) in the cabins and relevant comfort. In confirmation, it has been noticed that the cabins more prone to claims are usually those where the background noise is lower.
The matter is different concerning the acceptability thereshold for vibration levels in the accommodation areas, where they are to be measured and compared with limit values to be complied with. In fact, it is a common experience – acquired in the field of cruise ships and ro-ro vessels – that the compliance with vibration limits referred, in an certain frequency band, to the single harmonic components of the spectrum, does not entail any problem of habitability for the persons on board.
In other words, if the peaks of the spectrum remain all under a suitable threshold, the comfort for the passenger is secured. Furthermore, the comfort grows when the intensity of the single peak values of the spectrum decreases.
The limit value of 4mm/s has represented the starting point for the determination of an ever increasing level of comfort for the accommodation space and crew. This is clearly shown in the diagrams of fig. , where the progress over the years of the peak limit values of the specifications relevant to cruise ships and ro-ro vessels is represented.





Furthermore, as shown in fig. 6, the trend is to keep improving the hability standard in respect of the noise.The diagram shows that in more recent ships not only for the areas devoted to passengers but also for the space intended for the crew more strict requests are made in connection with noise.
For comparison, in fig. 6 are illustrated the typical vibration values (peak values) measured on board of cruise ships: it can be noticed that the values decrease moving away from the propeller, which can rightly be considered one of the primary sources of vibration on board the ships. It therefore can be appreciated that it is paramount to control the level of disturbance produced by the propeller if the after part of the ship is to be used, being it so attractive, for public areas and top-grade pax suites.

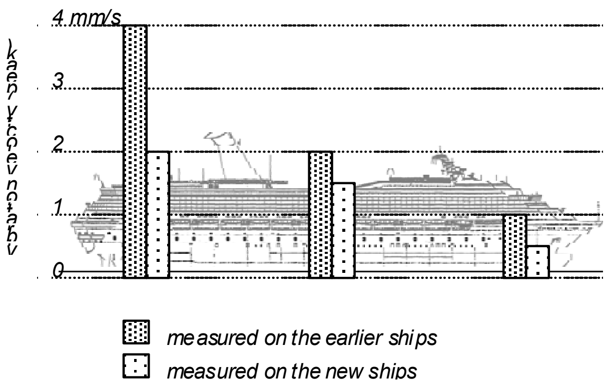


Fig. 6: *Vibration distribution measured in peak values on typical cruise ships.*

To quantify this aspect concerning the habitability of a cabin in connection with non-stationary noise, two types of sound disturbances are taken into consideration, which are correlated to the following indexes:

- sound insulation index,
- impact sound insulation index.

The first one, that is to say the sound insulation index, is connected with the noise transmitted by the adjacent spaces, caused by the human activity developed on the basis of the use allocation in said spaces. It is usual to make reference to such a source by classifying it as air noise and it can simply be the noise produced by a television set, if the contiguous space is another cabin, or by the music spread by the plants of the entertainment system difficult to foresee due to it’s variability.
The second one, the impact sound insulation index, is connected once again with the type of the adjacent space, but characterizes the disturbance caused by the sole impact noise on deck and is substantially a structural noise. It can be, for instance, the noise produced by the passage of persons in a corridor above the cabin, or a noise that is produced by the sport activities in a gym, and so on. Also this noise is difficult to quantify because its sources may be different and while it is strongly affected by the nature of the surface of the deck where it develops.
To consider also these sources, in order to determine with precision the quality of the comfort of a cabin, the Classification Societies set limit values for the foregoing indexes. In the following tables are shown the most significant values concerning the sound insulation index (Tab. 6) and the impact sound insulation index (Tab. 7).

Sound insulation index [dB]	Comfort class *1*			
	DNV	LR	BV	RINA
cabin to cabin top	46	45	42	40
cabin to cabin standard	41	40	40	40
cabin to public space	51	55	55	55
cabin to disco	65	60	65	65

Tab. 6: *Sound insulation indexes requested by some Rules for the assignment of the comfort class (for instance for comfort class 1) for passenger accommodation areas.*

Impact sound insulation index [dB]				
cabin below:	DNV	LR	BV	RINA
hard deck covering	60	60	–	60
soft deck covering (general case)	50	50	–	55
dance floor, stages	45	47	–	50

Tab. 7: *Impact sound insulation indexes requested by some Rules for the assignment of the comfort class for passenger accommodation areas.*

Such tests however do not provide the guarantee of the comfort for the passenger. A very eloquent example is that of the cabins for which a high level of insulation is foreseen in view of the fact that they are adjacent to a discotheque. In this case, the standard measurements of the quality indexes do not provide an actual quantification of the disturbance degree, since it is not possible to take into consideration the main characteristics of the music, that is to say the type of music and the volume of its spreading.
As expected the application of acoustical floor had achieved the best result solving/reducing disturbances in the cabins.

NOT ONLY NOISE INSULATIONS

Most claims were coming from passengers in quite cabins located directly above the showrooms. Many times the background noise in this cabins due to HVAC system is extremely low (about 37/38 dB (A)) and in this cases we expect an increase of noise levels when music is playing the global value is increased of 2-3 dB from the background noise so enough to disturb.
Obviously the low frequency content is dominating and it is well known to be very difficult to reduce.Now we are try to understand which are the best actions, farther on to have a very good insulation plan, that can be made in order to reduce the sound transmission from show rooms to the adjacent cabins.
As promised we want to start with the actions that can be made that we consider as fundamental.

A Good and Intelligent Arrangement of these Public Spaces

For example to have disco/show rooms in a well located position, far from the centre of the ship as example at the upper decks and without cabins around, is the only choice to avoid the problem.

Limited Level of Source Music

Another fundamental rule is played by the level of the music in the show rooms: if it is fixed to an “acceptable” level in order to avoid problems in the same show room and also in the cabins above or below.In our opinion this source level, expressed in dB (A), must be fixed in the technical noise and vibrations requirements.

Good Arrangement of the Loudspeakers

A good improvement can be archived, for example, with a good arrangement of the loud speakers trying to not fix them directly below or above the cabins and to use always efficient resilient mountings.

Electronic Noise Control

The system that can be used is to well set the existing equalizer (or an additional one). In this case the maximum level of sound in the room will not be affected, but the critical transmitted frequencies can be limited up to 5/8 dB in the full range of frequencies.
Another way is to use a dedicated “Comfort Monitoring System”; this system assist the disc-jockey in order to minimise the low frequency airborne noise coming from the music in discothèque to the near cabins. The low frequency noise level is measured with a microphone placed above the suspended ceiling in an exposed passenger cabin and the signal is transferred from a monitor box to an A/D converter and a Lab-top computer placed in the DJ booth.Data are stored and can be recalled for comparison. When a preset limit is exceeded an alarm is activated, giving at DJ an opportunity to reduce the gain setting of the music sound system.

Increase Background Noise in the Cabins

One more step to be made in order to have comfortable cabins, is to avoid having low background noise cabins above or below show room. Infect our experience suggest that the main complaints arise in the cabins with a low noise, generally generated from HVAC system. Passenger on board of cruise vessels may accept a higher background noise level (40 – 45 dB (A)) compared to hotel rooms ashore (25 – 35 dB (A)). For this reason we were obliged, with great wonder of our colleagues, to increase the background noise in the cabins in order to cover music.

ACOUSTIC POLLUTION

Acoustic pollution affects the external environment of the ship and thus the control of airborne and waterborne noise.

Noise in air

Some regulations relevant to the maritime coastal traffic are becoming effective, noise limits at the moment applied on Fast Ferry ships operating in Alaska, also at considerable distance from the ship, equal to 60 dB(A) at 305 m , are imposed. To control the noise radiated in the air, FINCANTIERI has adopted a new system of gas exhaust silencers called CSS – Compact Silencer System – that essentially entails a diligent control, performed in frequency, on acoustic performances and a significant reduction both of weight and load loss. Instead of installing for each exhaust gas line of the Diesel engines a sole silencer, the whole exhaust gas line is subdivided into silencing modules of three types, namely resistive, reactive and resistive-reactive, exploiting thus all the available space. The big advantage of this system is that the whole line is made up of silenced baffles that operate in the whole acoustic frequency field, the damping reached is rather precise, focused on the most important frequencies in order to obtain the control of the best acoustic result attainable. Is always possible to add another module, designed to the frequencies of interest, in order to improve the acoustic target

Noise in water

The purpose of the research has been, therefore, to identify, work out and assess, through first valid applications, a methodology allowing the acoustical optimisation of building solutions. Therefore, a ship model in AutoSEA2 has been created starting from that used for the static and dynamic structural calculation of the ship through a process of simplification to make it "lighter" but with the same function of transfer and an equal mass distribution. By crossing the spectrum of noise in the water at 10 knots and 10 m of depth with the thermo-graphic analysis in energy at relevant frequencies, at the level of hull sheathing, Fincantieri have been able to identify the source guilty of the global acoustic marking of the ship for that specific frequency band. Some real test has been performed on cruise ships

Conclusions

The paper deals with the control of noise and vibration on board of luxury passenger ships; particular problems as the entertainment noise and pollution noise has been discussed

REFERENCES

- **"Noise and vibrations: comfort on board of passenger ships"** International Symposiumon ship and shipping research , Genova 1992; R.Fabro, F.DeLorenzo, E.Lembo.