SOUND TRANSMISSION BETWEEN COUPLED ROOMS ONBOARD SHIPS

Tiberiu PAZARA[1], Nicolae ENESCU[2]

The current tendency regarding the noise onboard ships is to improve the working conditions in order to reduce the exposure to dangerous levels of noise. One of the solutions adopted in the machine compartment is a control room where the crew can monitor the installations without the exposure to high levels of noise. In this paper, is studied the propagation of the noise produced by the installations of ship's propulsion system to the control room. A series of simulations are made using a computer acoustic modelling software (ODEON) with various materials for noise insulation. Several appreciations and comparisons between these results and the measurement results onboard NS "Mircea" are made.

Keywords: ship, machine compartment, computer acoustic modeling, noise level

1. Introduction

The use of computer acoustic modelling programs for the propagation of noise has developed over the last decades. Although these programs were designed for simulations of auditoriums (e.g. theaters, conference rooms), recent developments allowed engineers to use the programs in simulations for industrial spaces [8].

There are different techniques used for studying sound propagation in enclosed spaces: FEM/BEM (Finite Element Method/Boundary Element Method) which led to several models: *Geometrical Acoustics Model*, *Statistical Acoustics Model*, *Diffusion Equation Model*, *Modal Expansion Method*. Other methods used to predict the noise level and acoustic parameters inside a room or an enclosure are *Ray Tracing Method* and/or *Image Source Modelling* [11]. The advantage of these models is that they are more accurate when predicting sound propagation for low frequencies compared to FEM/BEM models. Nowadays there are several software that can simulate noise propagation: *Odeon, CATT-Acoustic, Raynoise, EASE, CARA, Ramsete, Aurora*.

Noise produced onboard ships represents a continuous concern for engineers and ship designers and the noise standards are subject for a permanent

[1]Teacher Assistant, Department of Marine Electric and Electronic Engineering, Naval Academy „MIRCEA CEL BATRAN", Constanta, Romania, e-mail: tiberiu_pazara@yahoo.com
[2] Prof., Mechanics Department, University POLITEHNICA of Bucharest, Romania

debate [4] in order to improve working conditions onboard commercial ships and comfort conditions onboard passenger ships.

The use of computer acoustic modelling is not intended to replace the real tests or simulations with a scale model. However, the data that can be collected using computer acoustic modelling is very valuable. Using such kind of software one can change variables (e.g. absorption coefficient) very easy and can run an infinite number of simulations which cannot be done the same way on scale model or in situ.

The study of noise propagation onboard ships using computer acoustic software is very useful for engineers. To implement the noise standards onboard ships [1, 2, 3], ship designers need to simulate the propagation of noise. Through these simulations can be avoided future modifications onboard ships after they were launched.

2. Theoretical considerations

The methods used in ODEON are *Image Source Method, Ray Tracing Method, Secondary Source Method, Vector Based Scattering, Particle Tracing Method* [10, 12]. These methods are combined to simulate the noise propagation from Point Sources, Surface Sources and Line Sources.

In ODEON software are used point sources, line sources and rectangular surface sources. It is based on ray tracing method in combination with a secondary source radiation method for reflections [13]. The ray tracing method simulates how the noise is propagated from the sources: a large number of rays leave from the source then, when hitting a normal surface the particles return to the room; but when the rays are hitting a transmission surface, a fraction of the particles is transmitted in the adjacent room. For the simulations, ODEON takes into account the reflections and the scattering of the rays.

For each source, the noise level must be entered for each of the octave-band frequencies. Then, all the surfaces must be defined as normal or transmitting surfaces. For all the surfaces, the absorption coefficient must be entered. The transmitting area may be either a single surface or two parallel surfaces. For the transmitting surfaces the values of the transmission loss must be entered. For two coupled rooms, ODEON can compute the noise levels in both rooms which can be compared then with the real results from measurements.

To determine the noise level in the control room adjacent to the compartment with various noise sources, it is used the following equation [18]:

$$L_{receiver} = L_{source} - TL + 10\lg\frac{S_{wall}}{A} \quad (1)$$

$L_{receiver}$ – sound pressure level measured at receiver position

L_{source} – sound pressure level of the source/in the noise compartment
TL – transmission loss
S_{wall} – area of walls separating control room from the rest of compartment
A – absorption of control room

$$A = \alpha_1 S_1 + \alpha_2 S_2 + ... + \alpha_n S_n \quad (2)$$

$\alpha_1, \alpha_2 \ldots \alpha_n$ – absorption coefficients of control room surfaces
$S_1, S_2 \ldots S_n$ – areas of control room surfaces

The sound pressure level must be calculated for each of the nine standard octave-band frequencies: 31,5; 63; 125; 250; 500; 1000; 2000; 4000 and 8000 Hz.

In the next table are presented the areas of control room surfaces. The real values were introduced in AUTOCAD model.

Tabelul 1

Surface	Area (m^2)
Wall with 2 windows	10.4 = 5.2x2
Wall with 1 window	2.8 = 1.4x2
Side wall	2.8 = 1.4x2
Control panel	9.4 = 4.7x2
Door	1.08 = 1.8x0.6
Window	0.84 = 1.2x0.7
Ceiling	7.28 = 5.2x1.4
Floor	7.28 = 5.2x1.4

In a case of a wall with nonhomogenous structure the transmission loss can be computed using this equation [18]:

$$TL = 10\lg\frac{1}{\tau_{total}} \quad (3)$$

where $\tau_{total} = \dfrac{\sum_i \tau_i S_i}{\sum_i S_i}$

τ_i – transmission coefficient of the *i*th element
S_i – surface area of each component of the wall

$$\tau_i = \frac{1}{10^{\frac{TL_i}{10}}} \quad (4)$$

where TL_i – transmission loss of the *i*th element

In conclusion, the calculus for TL of a nonhomogeneous wall must be made for every 1/3 octave band frequency of the spectrum.

In the case of control room of machine compartment onboard NS “Mircea”, the transmission loss is:

$$TL = 10\lg \frac{1}{\dfrac{\dfrac{1}{10^{\frac{TL_1}{10}}} S_1 \cdot 3 + \dfrac{1}{10^{\frac{TL_2}{10}}} S_2 + \dfrac{1}{10^{\frac{TL_3}{10}}} S_3}{S_1 + S_2 + S_3}} \quad (5)$$

TL_1 – TL of 1 window
TL_2 – TL of door
TL_3 – TL of the remaining surfaces of the wall
S_1 – area of 1 window
S_2 – area of door
S_3 – area of the remaining surfaces of the wall

3. Simulation model and materials used in simulations

In these virtual simulations were used the measurements made onboard training-ship „Mircea", a ship with a MAK engine type 6M451AK and 3 MAN diesel generators type D2866E. The experiments were made in various conditions, when the ship was sailing in the Black Sea.

The microphones used in measurements were from Bruel&Kjaer type 4189-A-021. In the compartment, the microphones were placed near the generators and the engine, around 1.2m from them and 1.4m from the ground. The measurement positions were chosen after the working regime of the diesel generators. The diesel generators are connected in parallel and so they can run in various combinations (2 by 2 or all 3 together). The microphone in the control room was set in front of the windows and near the control desk.

The microphones were connected to the Machine Diagnostic Toolbox 9727 (Bruel&Kjaer) which contains a data acquisition system and a laptop with PULSE software. All the measurements were recorded and analyzed using FFT (Fast Fourier Transform) analysis and CPB (Constant Percentage Bandwidth) analysis.

The noise level in the compartment was measured during several trials under these conditions: the ship was sailing in the Black Sea – all the noise sources were running and two microphones were used in order to measure simultaneously the noise in the machine room and the noise in the control room.

The machine compartment onboard training-ship „Mircea" was modelled using AUTOCAD 12. This compartment is divided into two rooms: a large room, containing ship's engine, diesel generators and other equipments; a small room representing the control room where the control panel and the communication station with ship's bridge are.

The plan of the machine compartment is shown in figure 1.

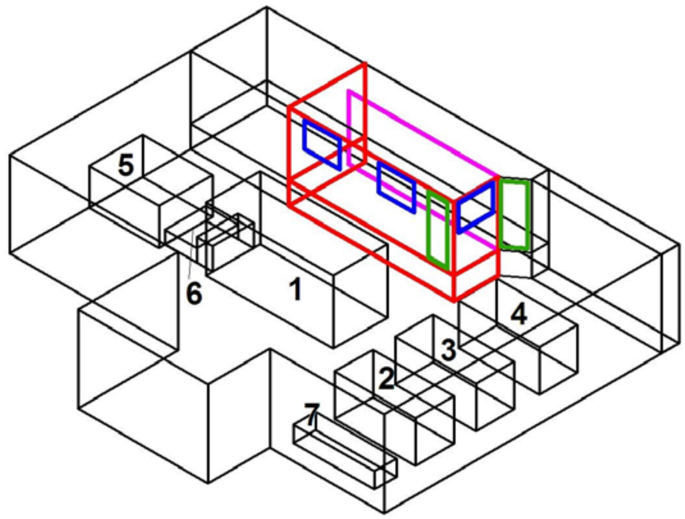

Fig.1 The machine compartment of NS "Mircea"

1 – engine; 2, 3, 4 – diesel generators; 5 – shaft line; 6 – reduction gear; 7 – back-up generator; green – doors; blue – windows; pink – control panel

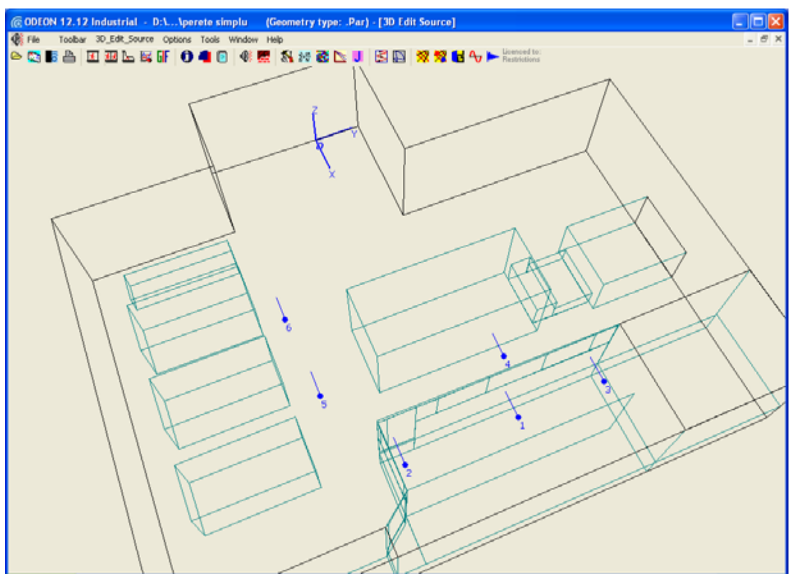

Fig.2 Microphones positions in machine compartment

In figure 2 is presented the distribution of the microphones (receivers) in the machine compartment.

The model is imported then in ODEON to make the virtual simulations. To perform the simulations, for each surface, noise source and receiver the acoustic parameters must be defined.

The scattering coefficient for all surfaces is 0.05.

The noise level for the sources was taken from the measurements made onboard during several sea trials.

For the surfaces of the compartment as well as for surfaces of the control room, the absorption coefficient α and the transmission loss TL must be defined individually.

In the next figures are presented the materials used for the simulations: the absorption coefficients [ODEON database] and the transmission loss values [9].

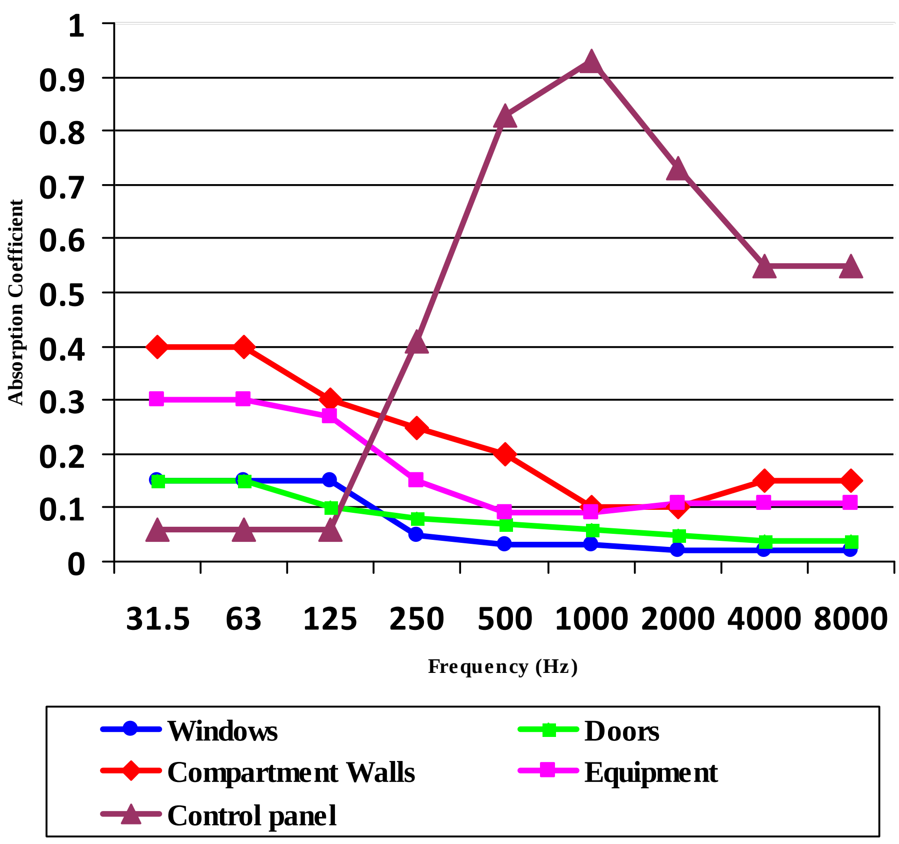

Fig.3 Absorption Coefficient of surfaces

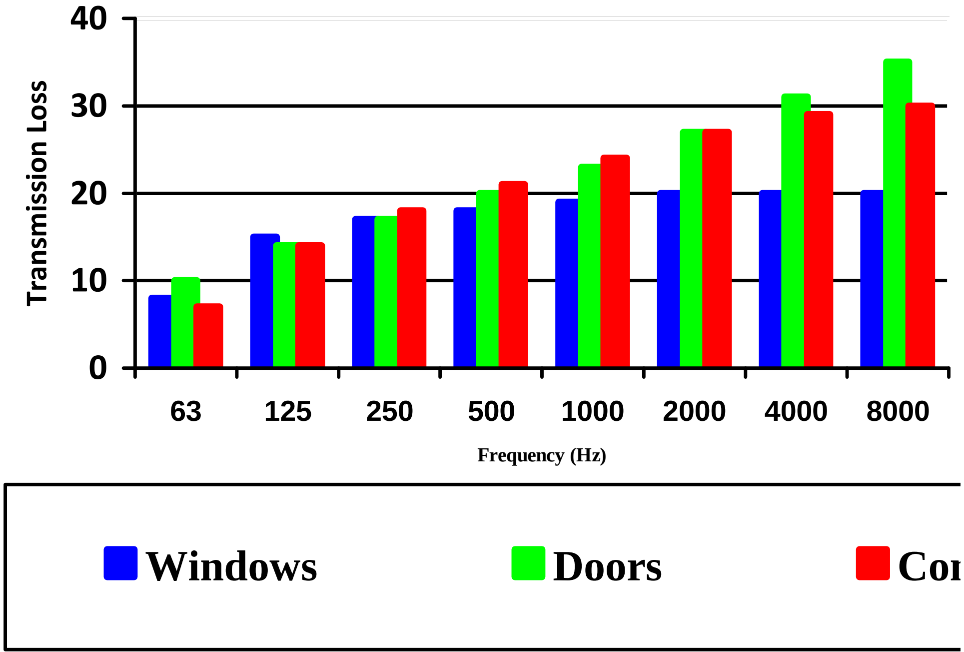

Fig.4 Transmission Loss of surfaces

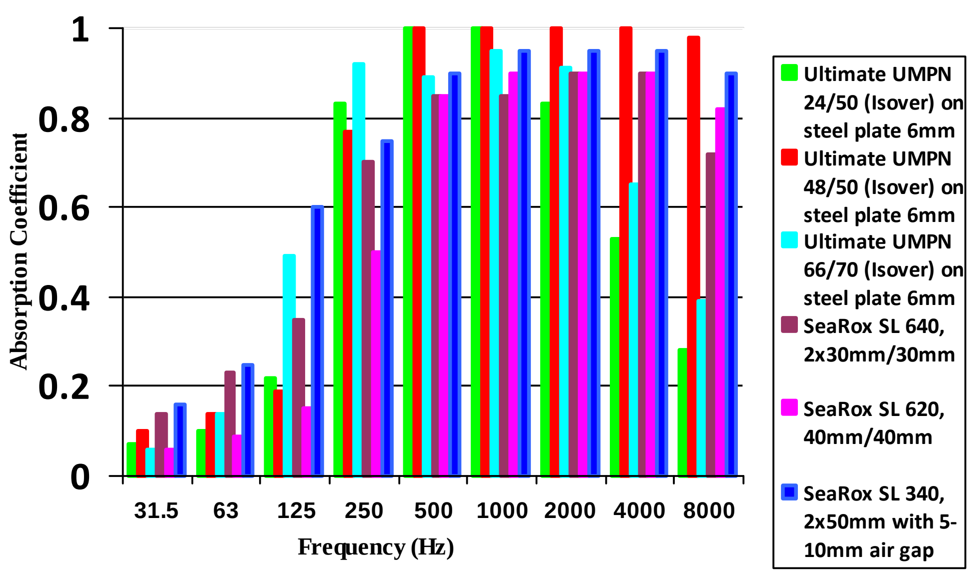

Fig.5 Absorption Coefficient of some of the materials used in simulations

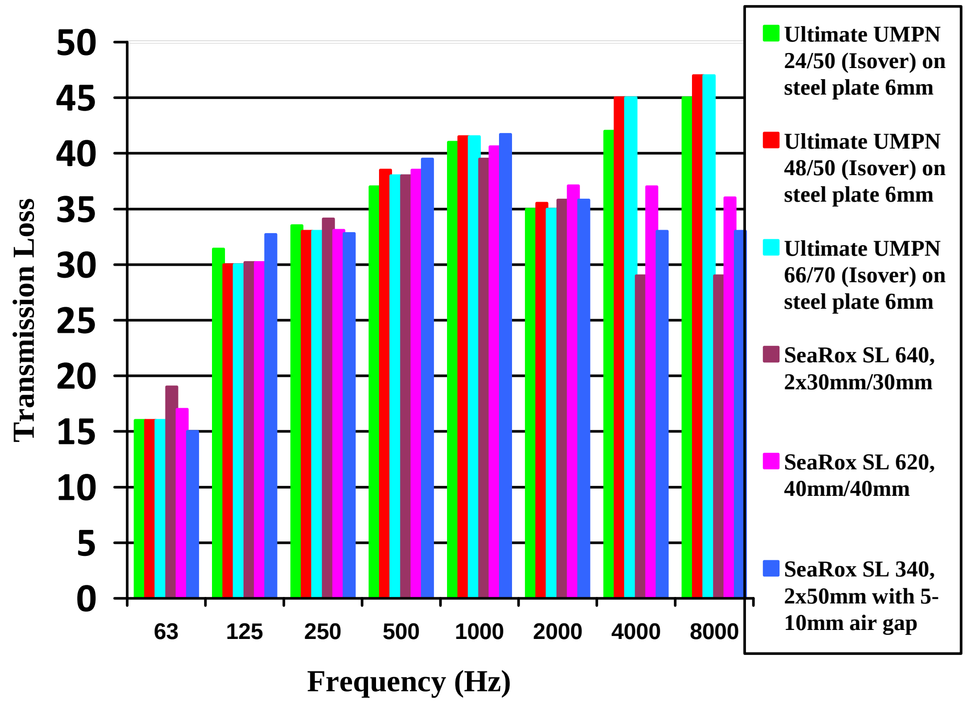

Fig.6 Transmission Loss of some of the materials used in simulations

The parameters of materials above were taken from manufactures [6, 7, 15, 16].

4. Results and interpretations

During the simulations, the materials of the walls of control room can be changed separately for each surface of the wall: windows, doors etc. The materials used in simulations are designed especially for marine industry. The characteristics of these materials include durability in severe environment, such a machine compartment onboard ships.

The transmission loss TL for a composite structure can be computed using formulas (3), (4) and (5). In figure 7 is presented the computed TL for the walls of the control room using the TL on octave bands for the following materials: windows – double glazed window 4/150/4 with absorbent reveal [9], doors – steel door with good seals, 50mm [9], wall – SeaRox SL 340 [6]. The results are compared with the TL of SeaRox SL 340.

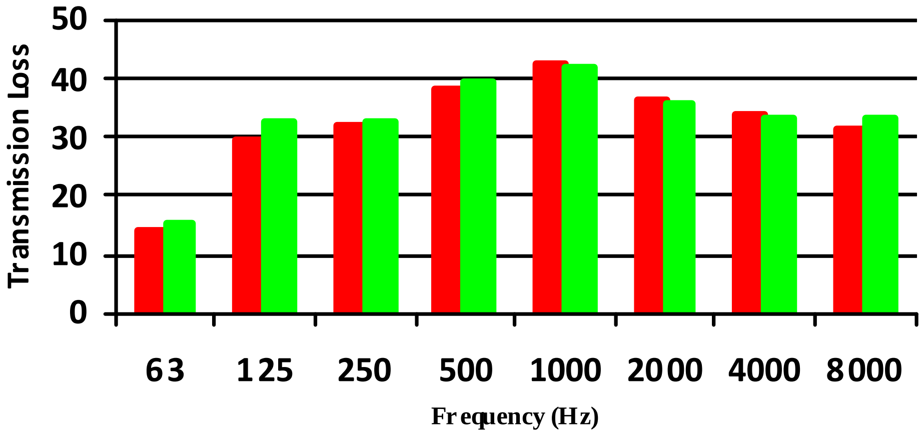

Fig.7 Transmission loss: red – calculated values; green – SeaRox SL 340 values

It is easy to observe that there are very little differences between the computed TL and TL of the SeaRox SL 340.

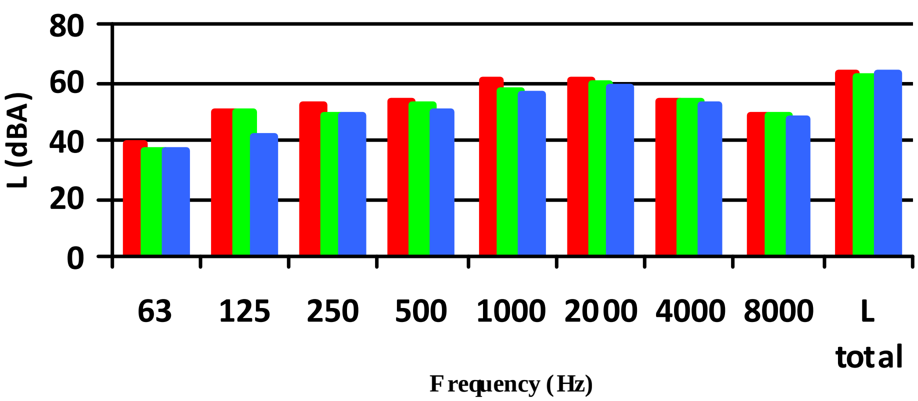

Fig.8 Noise level in the control room: red – simulated values; green – calculated values disregarding the absorption of walls; blue – calculated values with absorption of walls

In figure 8 are presented the values of noise level in the control room: the values simulated with ODEON and the values calculated using formulas (1) and (2). In the calculations it was used the computed TL. Also, in the low and medium frequency domain it can be noticed that the differences between simulated results and the computed results are approximately constant, but existing a bigger difference for the 125Hz band. For frequencies above 1000Hz, the noise levels are almost equal.

In the next simulations the material for the walls of the control room wasn't changed, it remains SeaRox SL 340.

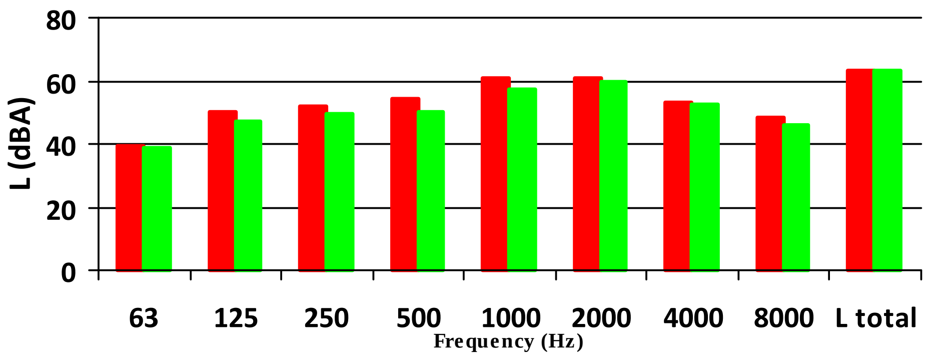

Fig.9 Noise level in the control room: red – simulation with TL for windows from [9]; green – simulation with TL for windows from Bies (6+5mm glass, 100mm cavity)

In figure 9 are presented the results of the simulation using a different material for windows. It can be noticed that a different window with higher TL doesn't decrease the noise level.

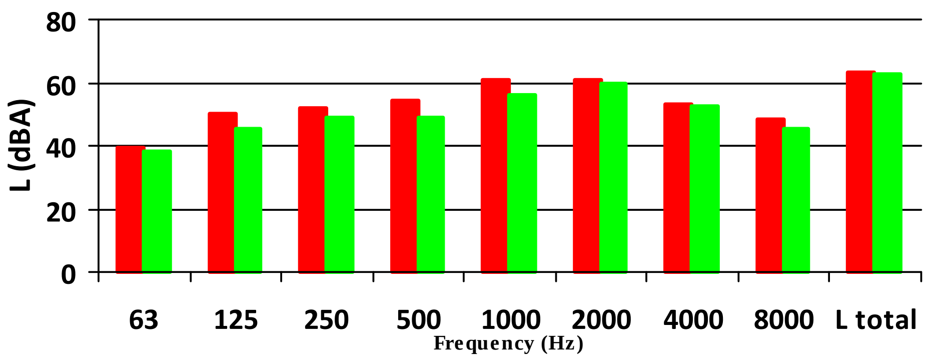

Fig.10 Noise level in the control room: red – simulation with TL for windows and doors from [9]; green – simulation with TL for windows and doors from Bies (6+5mm glass, 100mm cavity; typical proprietary acoustic door)

In figure 10 are presented the results of the simulation where the materials for windows and doors were changed. Again, the change doesn't decrease the noise level in the control room.

After many simulations where the TL of the windows and doors were changed, it can be concluded that the use of materials with higher absorption coefficient and transmission loss for these surfaces doesn't decrease the noise level inside the control room. Some of the results are presented in figure 11.

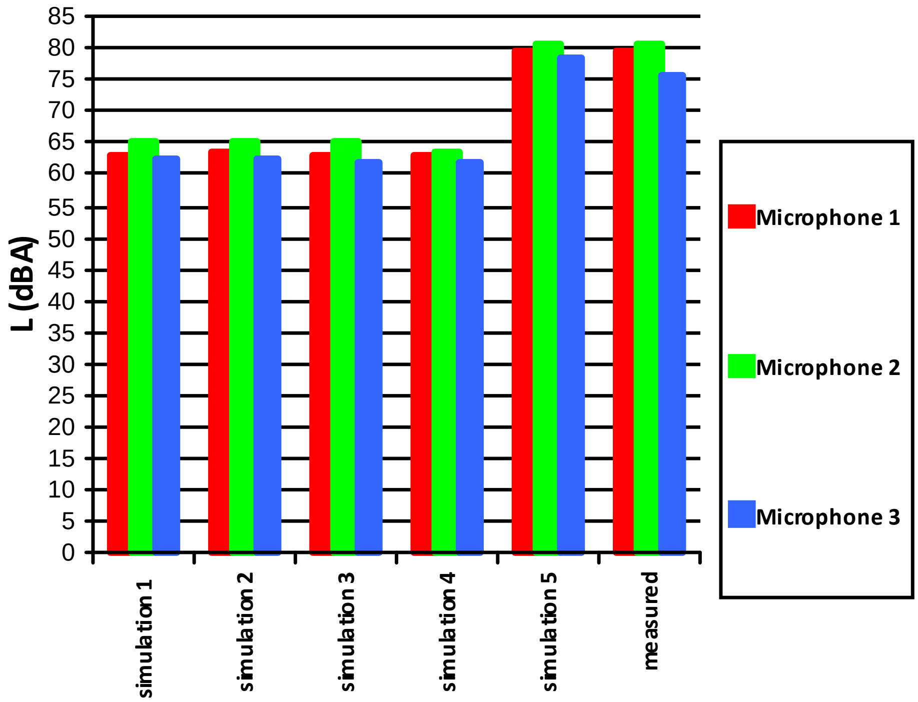

Fig.11 Noise level in the control room: red – microphone 1 in middle of control room; green – microphone 2 left of control room; blue – microphone 3 right of control room

Simulation 1: walls (SeaRox SL 340), windows [9], doors [9]
Simulation 2: walls (SeaRox SL 340), windows [18], doors [9]
Simulation 3: walls (SeaRox SL 340), windows [18], doors [9]
Simulation 4: walls (SeaRox SL 340), windows [18], doors [18]
Simulation 5: walls (actual material onboard), windows [18], doors [18]

The differences between simulation 5 values and measured values are very small. There is a decrease of the noise level, but only for microphone 3. So, the surface that must be treated with better sound-absorbing materials is the surface of walls.

In the next series of simulations presented in figure 12 we wanted to determine how the noise level inside the control room changes when the walls of the control room were covered with these materials:

Simulation 1 – Isover Ultimate UPMN 66/70
Simulation 2 – Isover Ultimate UPMN 48/50
Simulation 3 – SeaRox SL 620 40mm
Simulation 4 – SeaRox SL 340 2x50mm

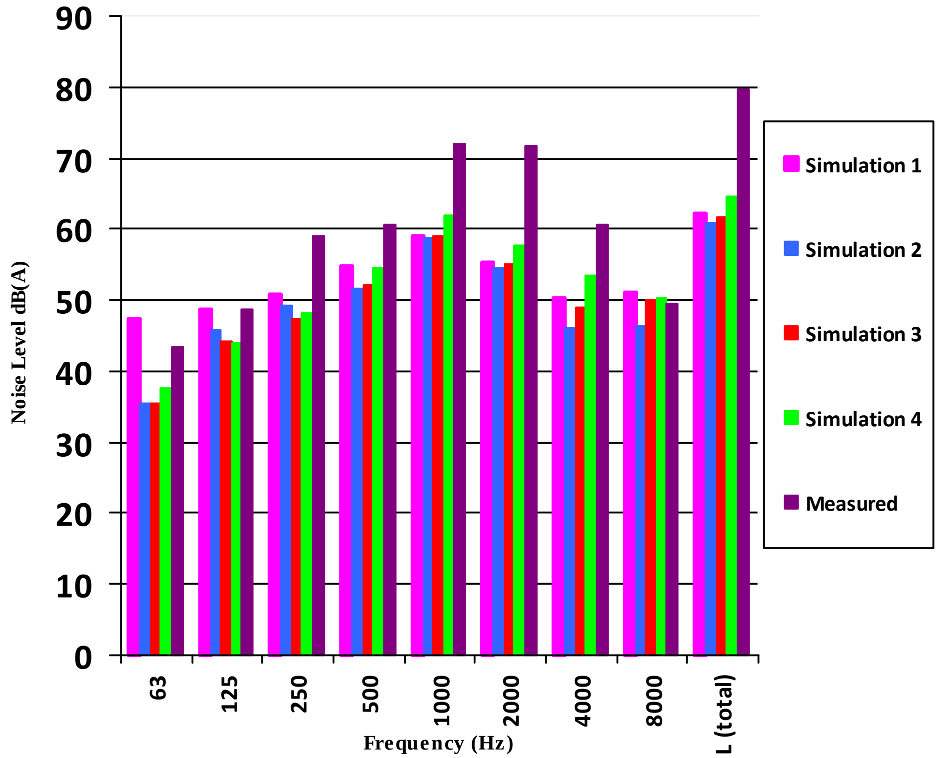

Fig.12 Noise level in the control room: comparison between different simulation results and measured results

From the simulations presented in figure 12, it can be noticed that the main reduction in the frequency range 250-4000Hz. For frequency below 250Hz and above 4000Hz, the sound pressure level remains close to the one measured.

In the control room the measured noise level is 78-80 dBA, a value that exceeds the limit of 75 dBA from the international standards. This limit is a recommended one, not a value to be reached. That’s why the noise level obtained after the application of insulation treatments must be lower than this value. In the simulations, the noise level in the control room is in range of 62-64 dBA. These are good results because during the installation of the materials can appear errors which are translated in higher noise levels. Also, noise can propagate through other paths: flanking transmission, sound leaks, indirect transmission of sound.

In figure 13 is presented the distribution of noise levels in the machine compartment in the simulation with SeaRox SL 340.

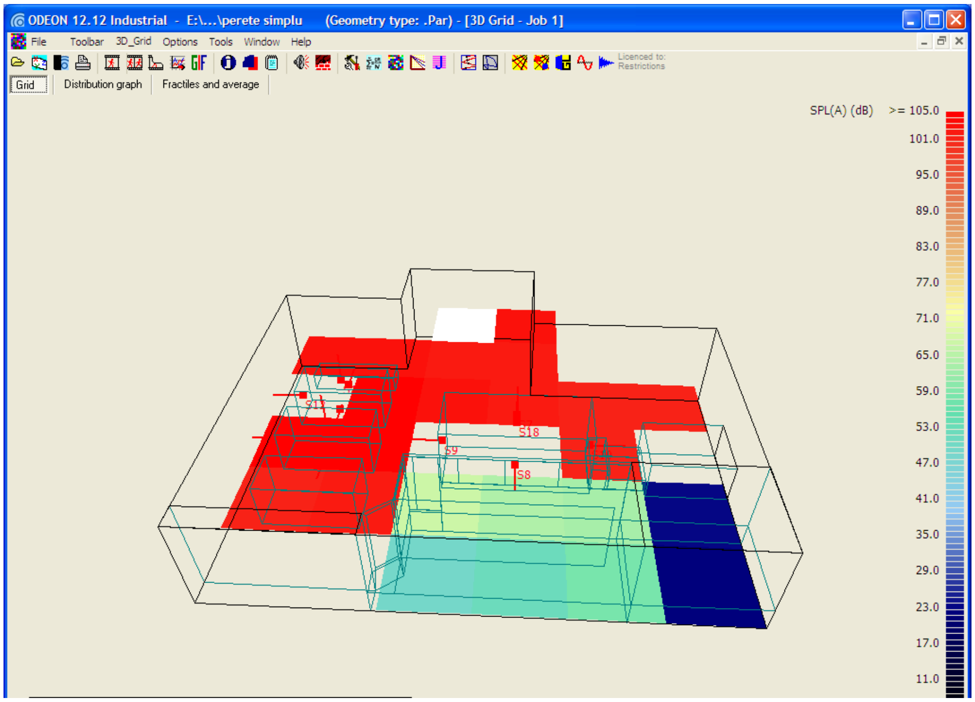

Fig.13 Distribution of noise level in machine compartment

5. Conclusions

In this paper is presented the use of a computer acoustic software – ODEON – to simulate the propagation of noise in the machine compartment onboard a ship. This compartment has a large room where are located the engine, diesel generators and other equipments and a control room where are located the control panels and communication station. The noise produced by these sources is propagated not only to the control room, but also to the entire ship. Even though the crew is obligated to wear headsets in the machine compartment, in the control room must be a low noise level so that communication and observation of the equipments could be made without helmets or headsets.

Here is studied how the noise is propagated from the large noise sources (engine, diesel generators) to the control room situated in the machine compartment onboard training ship „Mircea“. Based on the measurements made onboard the ship during several trials in the Black Sea, it was created a map of the noise sources. To improve the attenuation of noise in the control room, sound-absorbing materials must be applied to the walls of the room. In order to choose the right material, it is very useful to make virtual simulations with different materials. This way is eliminated the testing of the sound-absorbing materials directly which is time consuming. An „in situ“ test means that all the installations onboard must running (the ship must sailing) and the opportunities for such a test are very small. Using a simulation software, these problems can be overcome. Also, through enough simulations, one can choose the right materials for insulation and also the right design, configuration and dimensions of a compartment. In the end, the success of a good insulation will depend only on the correct installation of the sound-absorbing materials onboard.

The future standards intend to reduce the noise limits. This means that the acoustic treatment of the control room must be improved. The solution of using computer acoustic modelling software may be a major part in reduction of noise aboard ships and with lower costs.

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