STATISTICAL ENERGY ANALYSIS METHODS IN MARINE APPLICATIONS

MATEUSZ WERYK

Centrum Techniki Okrętowej S.A.
Ośrodek Mechaniki Konstrukcji Okrętu
Rzeczypospolitej Av. 8, Poland
e-mail: Mateusz.Weryk@cto.gda.pl

In this paper, general overview of Statistical Energy Analysis (SEA) method is presented, especially, SEA method in marine application is described - noise prediction on board and noise emission into the environment (air and water). There are two examples of the use of SEA.

INTRODUCTION

Great number of structures is subjected to vibration and acoustic excitation at high frequencies. The most famous method in theoretical modelling and analyzing high frequencies is Statistical Energy Analysis (SEA) method. This method is “energy-based” in contrast to classical methods that are based on quantities such as force and displacement. For many years, people were predicting noise on board using empirical methods such as:

- multiple regression method – based on statistical model
- physical model method describing vibro-acoustic effects in ship’s structure
- Finite Element Analysis (FEA) and/or Boundary Element Analysis (BEA) method

SEA provides an alternative form of model that represents the average response behaviour of a population of systems. The vibrational state is expressed in terms of vibrational energies of individual components, where applied excitations are expressed in terms of input powers and the couplings between components are expressed in terms of energy flows.

SEA has some key features which make this method very attractive as far as customer is concerned:

- the power – energy relation is not so sensitive to small parameter change
- energy quantities can be averaged more easily

- short modelling time

1. OVERVIEW OF SEA

Statistical Energy Analysis method is based on energy dissipation. “Statistical” means, that the variables are extracted from statistical population and all results are **expected** values. The main idea of SEA method is that one has to divide analyzed structure into “subsystems”. All energy analysis is done between those subsystems. What is the subsystem? It’s a part or physical element of a structure (system) being analyzed. To be a subsystem one has to comply with some conditions as:

- part of structure considered as a subsystem should have a capability of vibrating *quite* independently from other parts, where *quite* means that as long as the element is not separated from the structure its vibration is not independent.
- part of structure considered as a subsystem should vibrate in resonant mode, i.e. if the excitation is suddenly switch off, the vibrational energy stored in subsystem should decay rather than drop to zero immediately.

The actual development of SEA started in the early 1960’s with the problems in aerospace engineering. In the early 60’s R.H. Lyon, G. Maidanik and T.D.Sharton introduced SEA method as a general technique of noise prediction and structure elements sound radiation of complex mechanical parts. In 1970’s R.H.Lyon has published his key work about SEA. In next years, SEA method was evolving. Among many applications where SEA was used, there are four major:

- cars
- trains
- ships and offshore structures
- aeroplanes

2. SEA MATHEMATICAL BASICS

Considering one single subsystem, any excitation acting on this subsystem can be characterized by the resulting power input P_i into subsystem (fig.1). After power injection, there is vibrational energy W_i stored in subsystem. There will be naturally a power loss P_{ii}. And this is how one can relate power loss to the stored energy by the damping loss factor η_i:

$$P_{ii} = \omega \cdot \eta_i \cdot E_i \qquad (1)$$

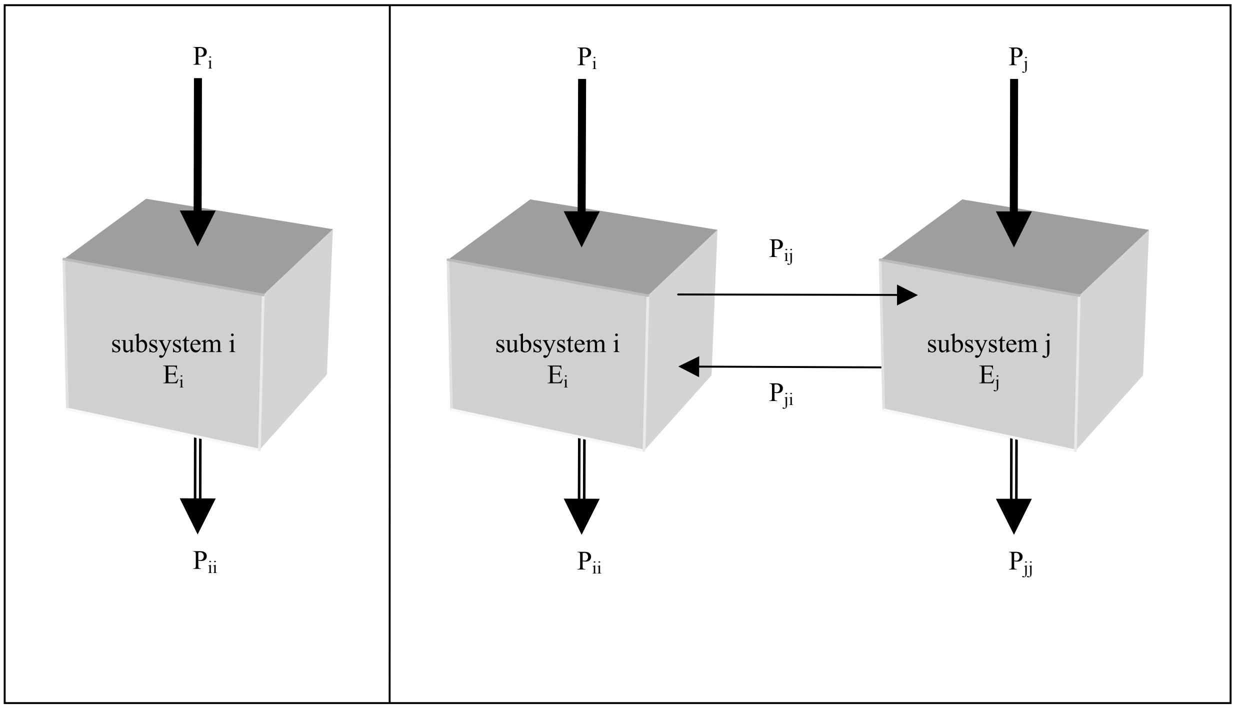

Fig.1 Single subsystem (left) and coupled subsystems (right)

Assuming that analysis is restricted to steady state, power input equals power loss:

$$P_i = P_{ii} \tag{2}$$

Considering now second subsystem 'j' coupled to the first one 'i' (fig.1), the same power balance would hold for both subsystems 'i' and 'j'. Because of coupling, subsystems share their vibrational energies, so there is a power flow from subsystem 'i' to subsystem 'j'. From the point of view of subsystem 'i' power flow P_{ij} is a power loss and power flow P_{ji} is a power gain.. The same thing with subsystem 'j'.

$$P_{ij} = \omega \cdot \eta_{ij} \cdot E_i \tag{3}$$

An example of four subsystems is shown below (fig.2). There is only power input to subsystem 1. This power input is equal to the sum power losses (due to dissipation and coupling) for whole system minus the power gains coming from the subsystems 2 and 3. One can establish power balances in the system:

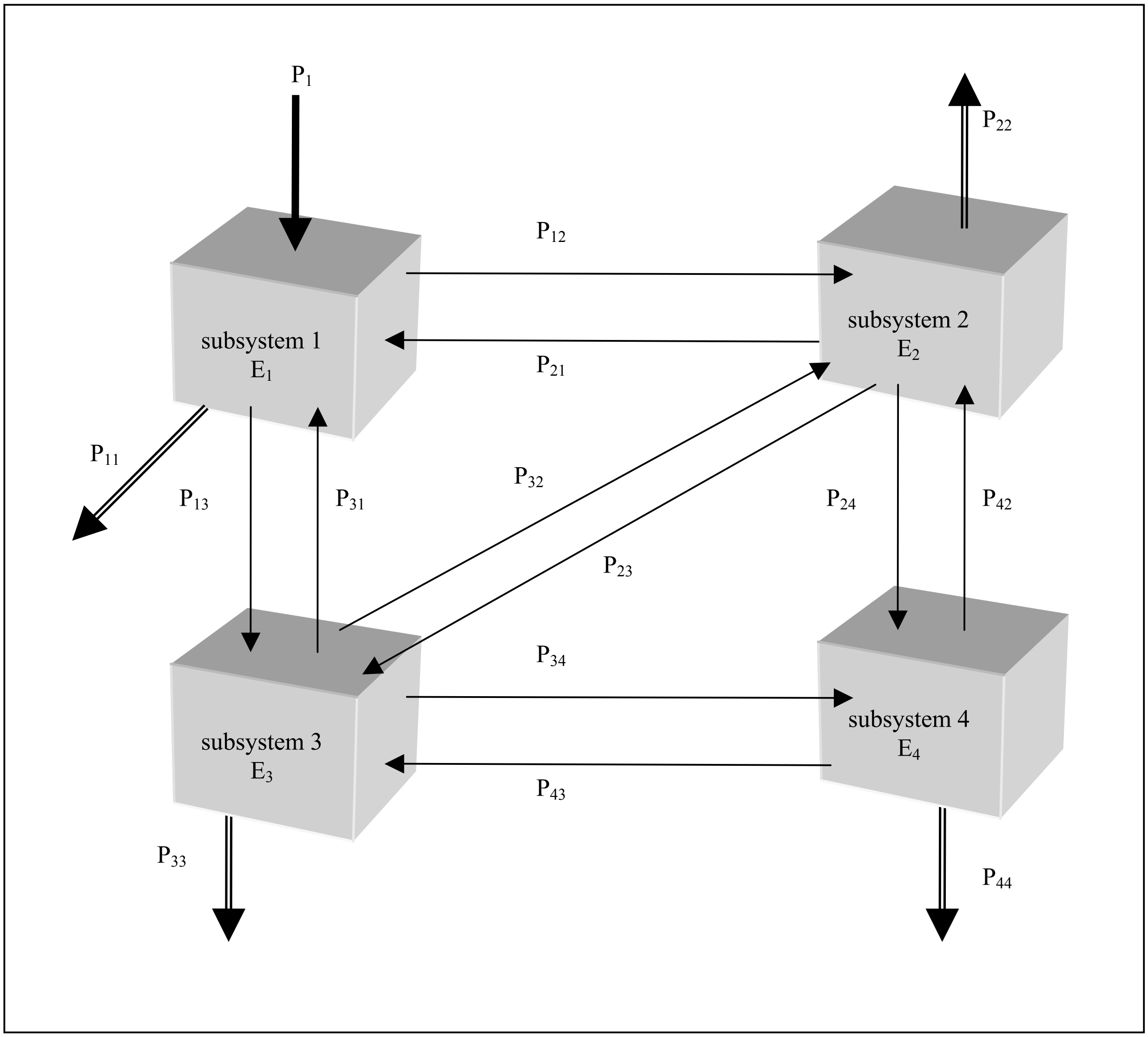

Fig.2 Four subsystems

$$P_1 = P_{11} + P_{12} + P_{13} - P_{21} - P_{31} \tag{4}$$

$$0 = P_{22} + P_{21} + P_{23} + P_{24} - P_{12} - P_{32} - P_{42} \tag{5}$$

$$0 = P_{33} + P_{31} + P_{32} + P_{34} - P_{13} - P_{23} - P_{43} \tag{6}$$

$$0 = P_{44} + P_{42} + P_{43} - P_{24} - P_{34} \tag{7}$$

Having in mind equations (1) and (3), one can substitute above equations into damping and coupling loss factors and vibrational energy.

$$\omega \cdot \begin{pmatrix} \eta_{11} & -\eta_{21} & -\eta_{31} & -\eta_{41} \\ -\eta_{12} & \eta_{22} & -\eta_{32} & -\eta_{42} \\ -\eta_{13} & -\eta_{23} & \eta_{33} & -\eta_{43} \\ -\eta_{14} & -\eta_{24} & -\eta_{34} & \eta_{44} \end{pmatrix} \cdot \begin{pmatrix} E_1 \\ E_2 \\ E_3 \\ E_4 \end{pmatrix} = \begin{pmatrix} P_1 \\ 0 \\ 0 \\ 0 \end{pmatrix} \tag{8}$$

The diagonal elements of the loss factor matrix are called the total loss factors, as they are the sum of all coupling loss factors that are associated with power losses for the given subsystem:

$$\eta_{ii} = \eta_i + \sum_{j,j \neq i} n_{ij} \tag{9}$$

3. SHIP MODELLING

Noise in compartments is a result of different kind of equipment and machinery influence. These noise sources are commonly located in aft part of ship (i.e. ro-ro) or in the midiship part (i.e. ferry), which affects all compartments. The most important noise sources on a ship:

- main engine and generator sets
- gear
- propellers
- exhaust systems with engine room ventilation
- auxiliary mechanism such as hydraulic systems, pumps
- ventilation and air-conditioning systems

Participation of particular noise source on result noise in compartment depends on a ship structure, power and structure of mechanisms, their foundation, distance between noise source and analyzed compartment. In compartments, in which noise sources are installed (i.e. engine room, pump room), sound pressure level is generated by machines' air-noise. In compartments that are at some distance from noise sources, there is mostly structure-borne noise. Generally, noise on ship is mostly structure-borne noise. Air borne noise is present especially in compartments, which are adjacent to engine room, exhaust system, or on decks in the chimney neighbourhood (fig. 3).

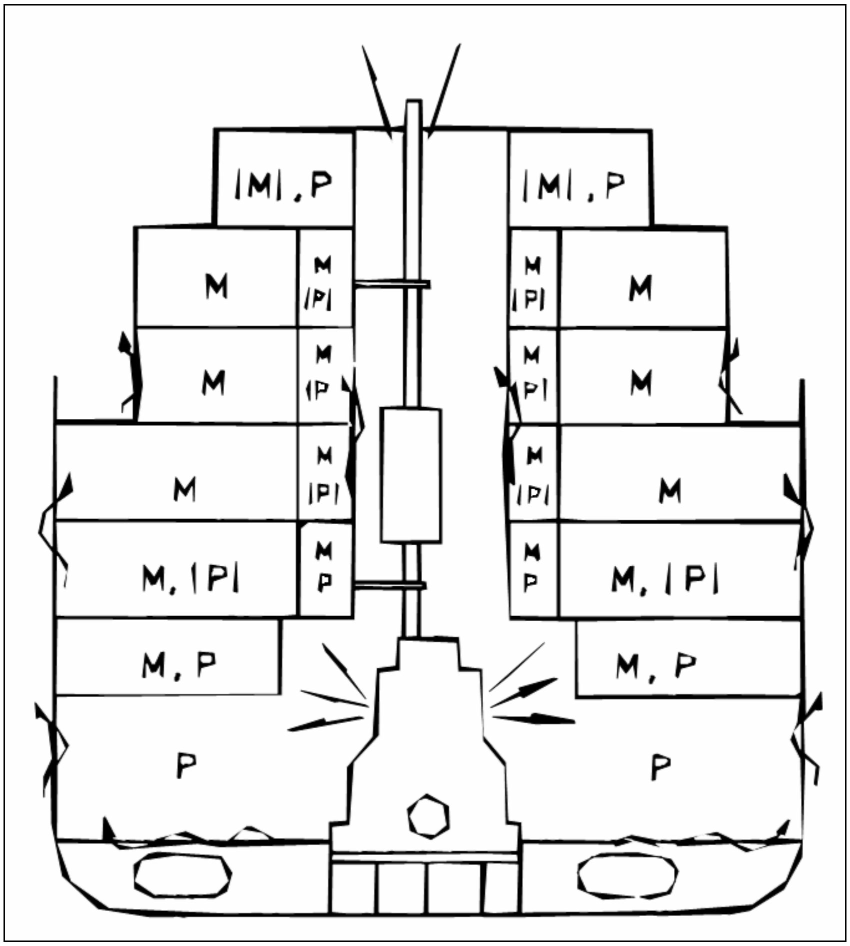

Fig.3 Structure-borne (M) and air-borne (P) noise influence on compartments

The main problem in modelling ship in SEA is determining the subsystems. In Chapter 2 definition of subsystem was given. In marine application determining the subsystem is quite complicated because of a number of subsystem's couplings. Therefore, determining the subsystems is more a matter of experience and ship's noise and vibration knowledge.

Building SEA model starts with importing geometry into the AutoSEA2 program (i.e. from Nastran), as it is shown on fig 4. Then one creates subsystems (i.e. beams, rods, plates, shells, cavities), add material properties (i.e. fig 5) and set the loads and excitations.

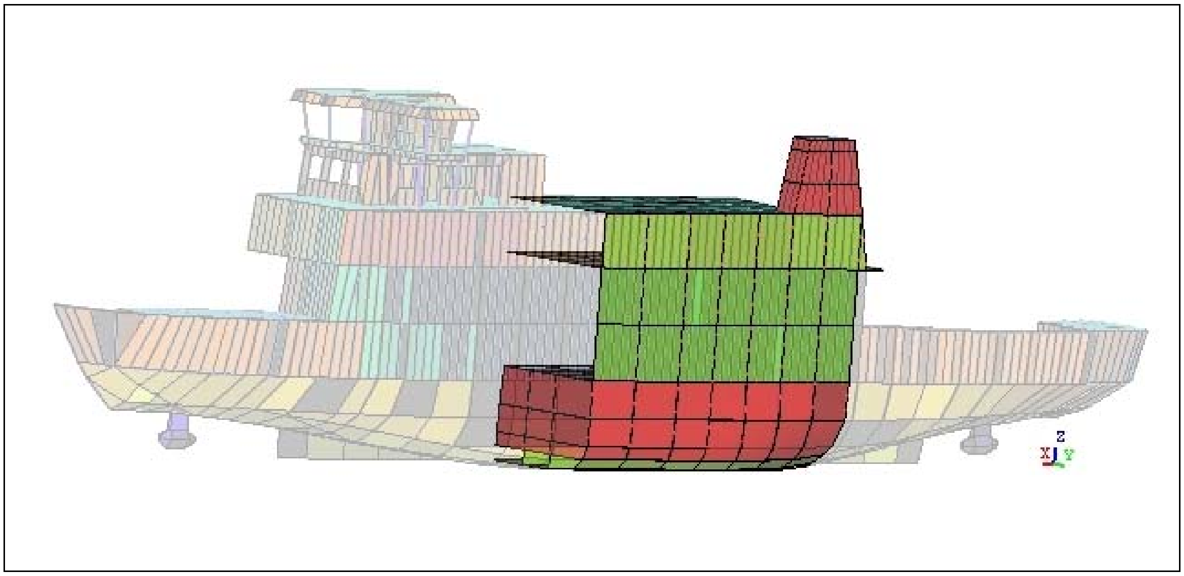

Fig.4 Example of imported Nastran data and SEA midship part

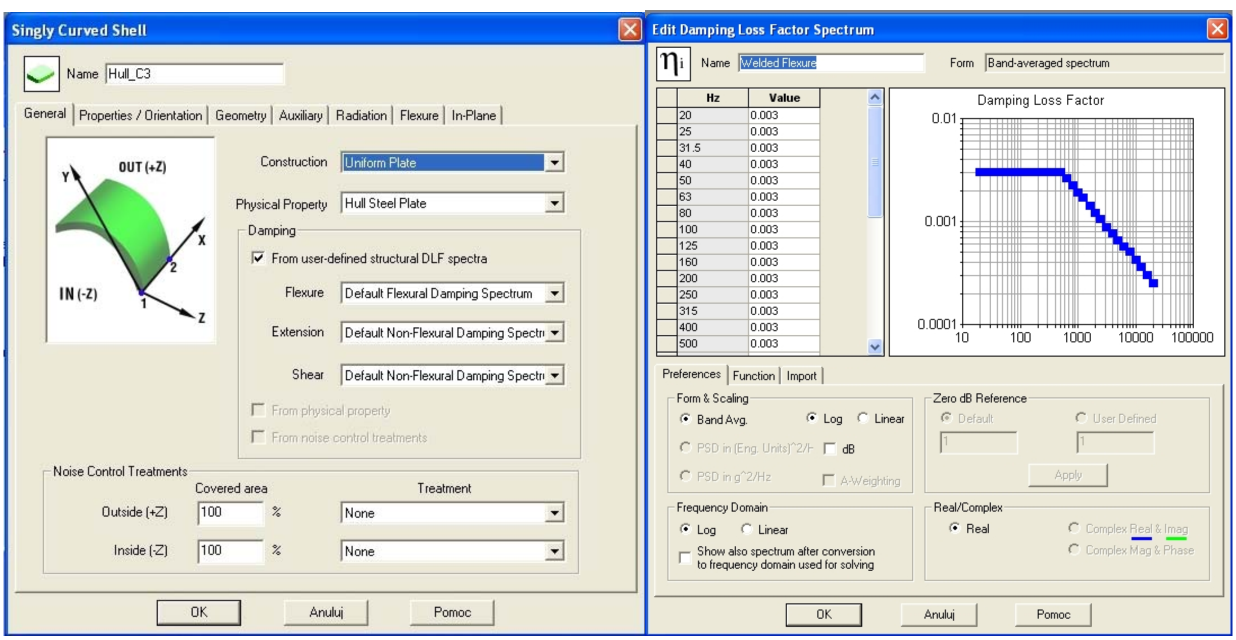

Fig.5 Example of plate properties (left) and damping loss factor (right)

After solving SEA matrix one get results such as energy flow and energy thermogram:

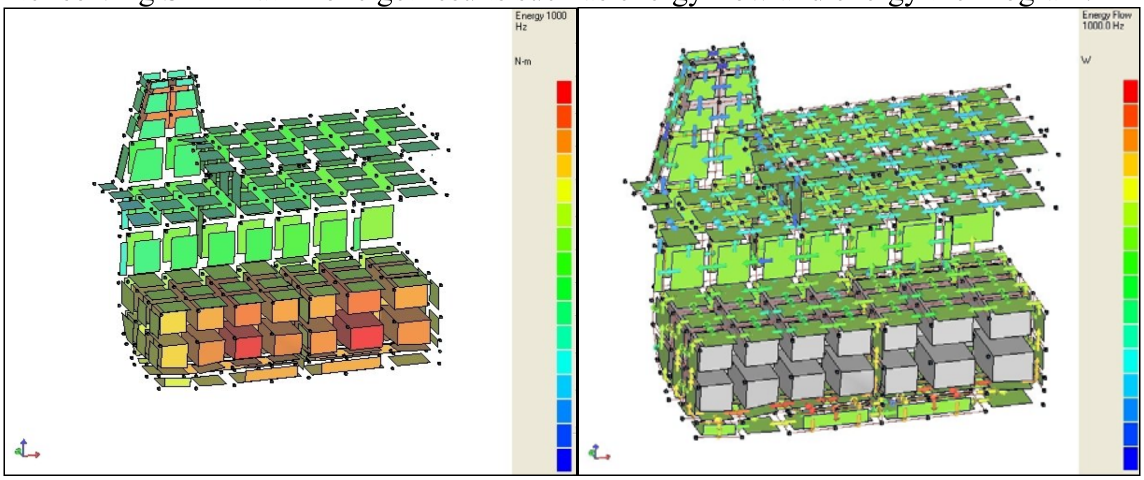

Fig.6 Energy thermogram (left) and energy flow (right) result chart

Below, there is an example of part of a ship model made in AutoSEA2. On the grounds of this example one will present SEA model design process and analysis.

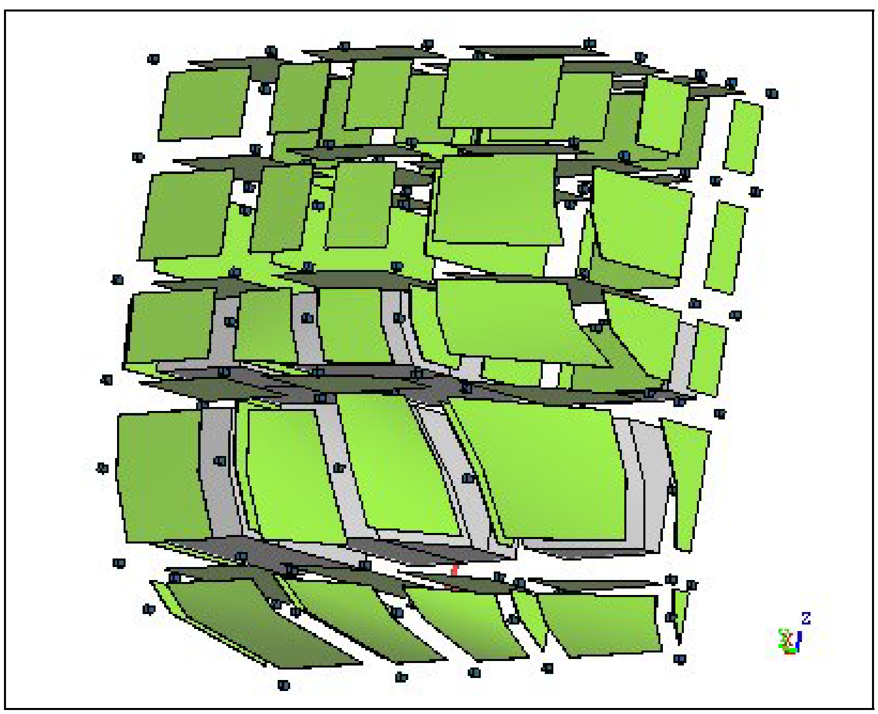

Fig.7 Ship example in AutoSEA2

As it was said above, engine room is a major vibrational energy input place. Below on fig.8, force input characteristic of an engine which was applied to described model is shown.

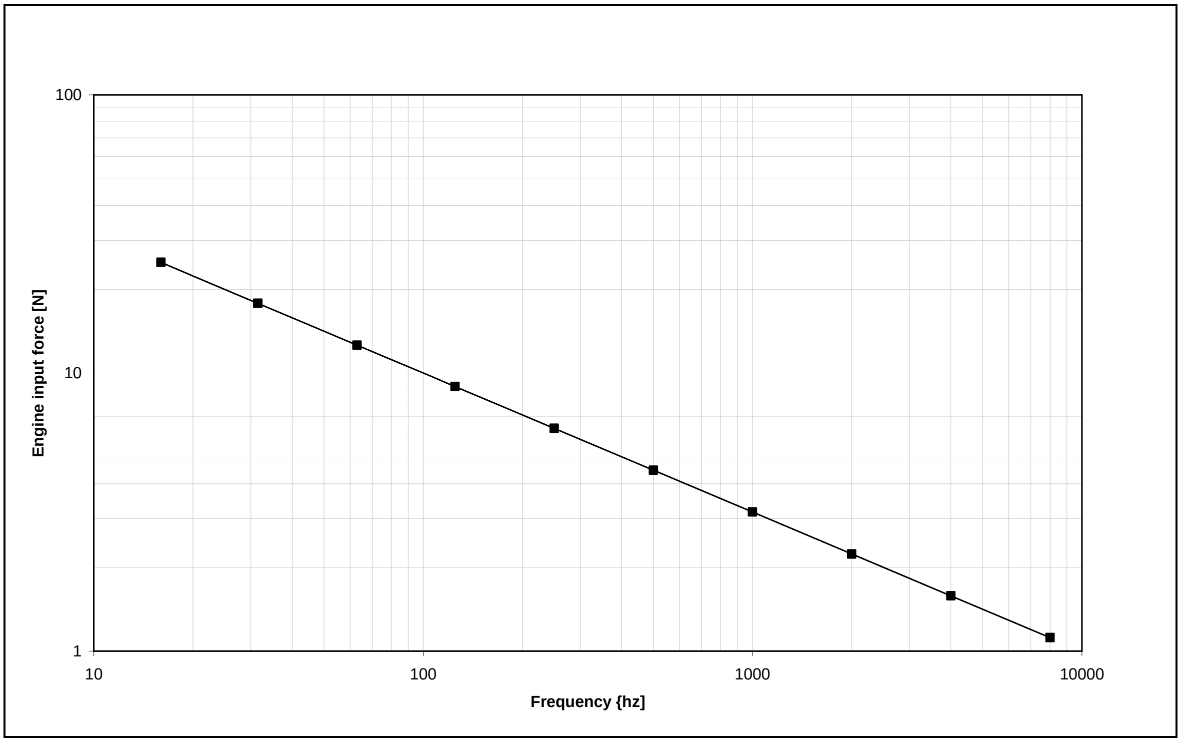

Fig.8 Engine input force

Model main data:

- engine room with poor absorption coefficient
- high energy radiation of plates enclosing engine room

In order to damp high-energy radiation one had to add an engine support isolator. After that, model was recalculated and plates' velocities results were presented. Plates calculation results before and after installing isolator are shown on fig.9. As one can see, isolator installation has given an app. 20 dB improvement. On fig.10 energy flow is presented. This shows the net power exchanged at every connection between a junction and a subsystem. The net power is represented by arrows of varying colour depending on the amount of power going into the junction from the subsystem or into the subsystem from the junction. On fig.11 there is an energy thermogram at 1000 Hz presented. This is very important result as far as energy dissipation is concerned.

Another interesting application is estimating sound pressure level (sound radiation) at given distance in water (fig.12). On given example there's a receiver point placed at about 20m distance from ship. On fig. 13 there is sound pressure level result in sea water.

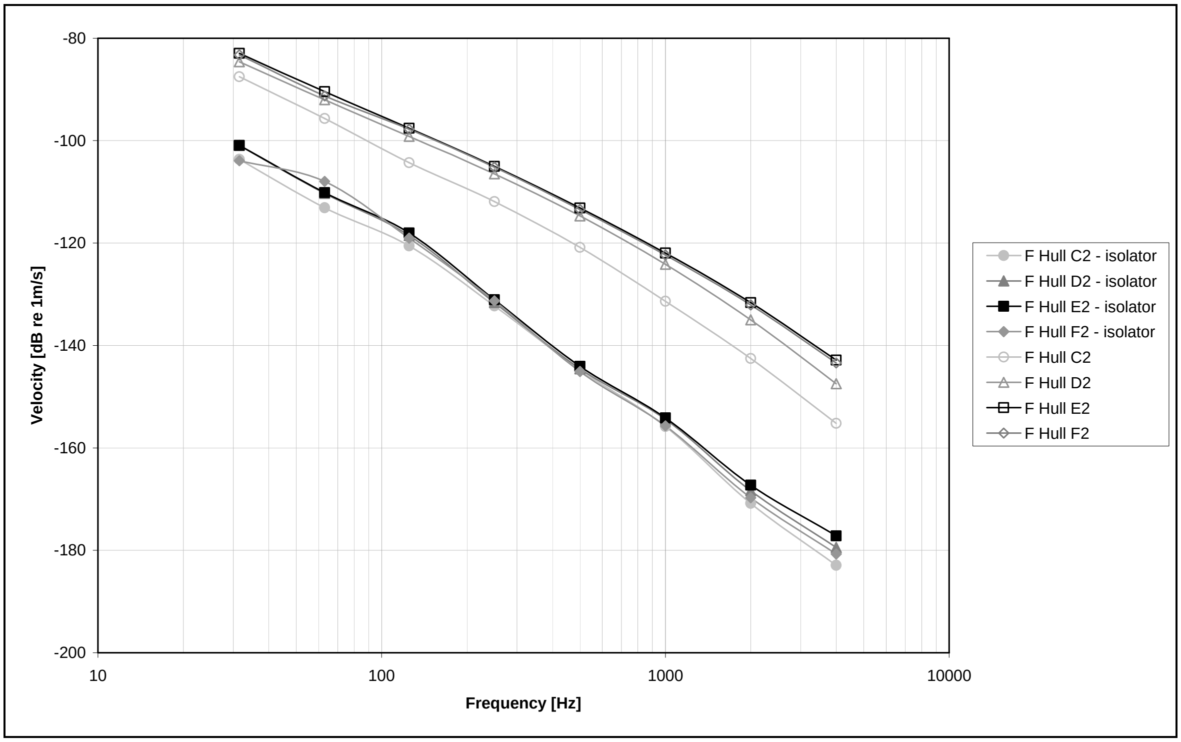

Fig.9 Plates velocities before and after installing engine support isolator

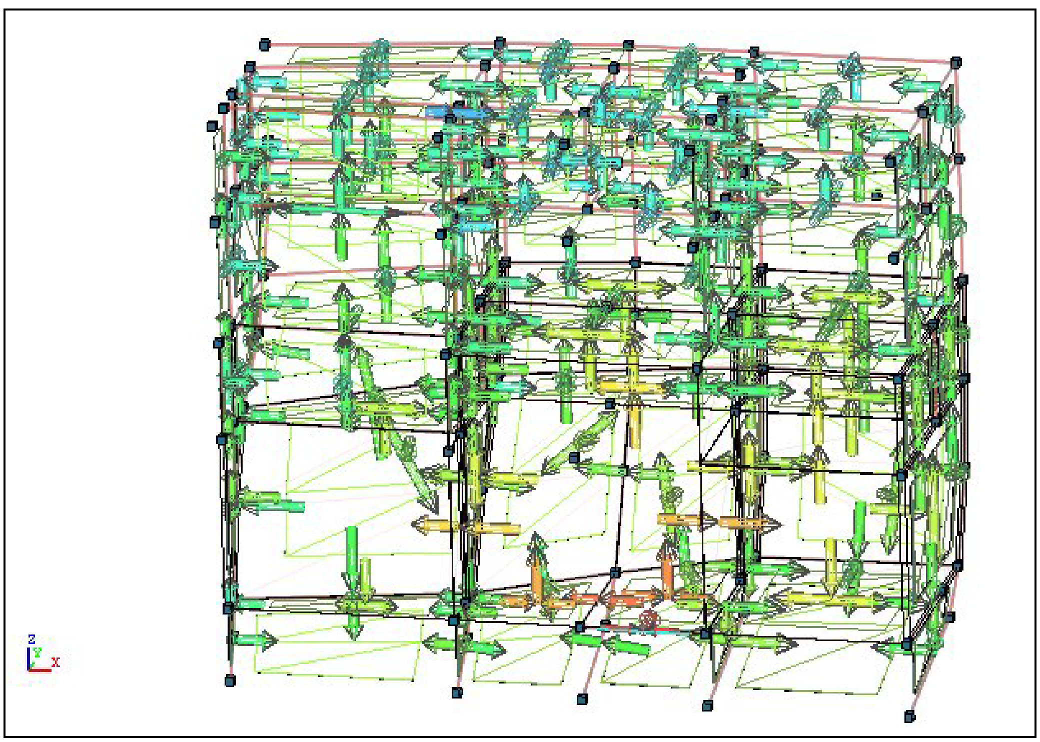

Fig.10 Energy flow at 250Hz

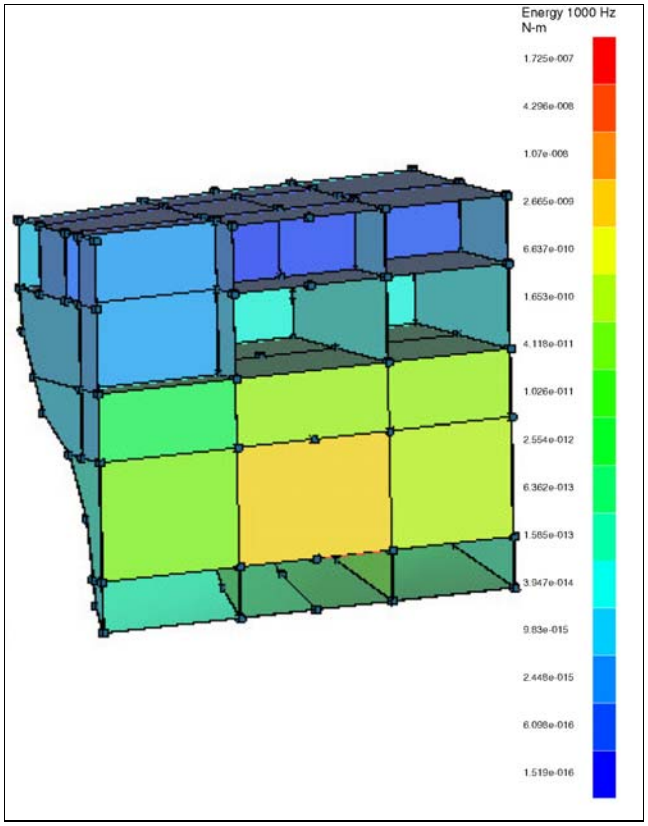

Fig.11 Example of energy flow thermogram at 1000 Hz

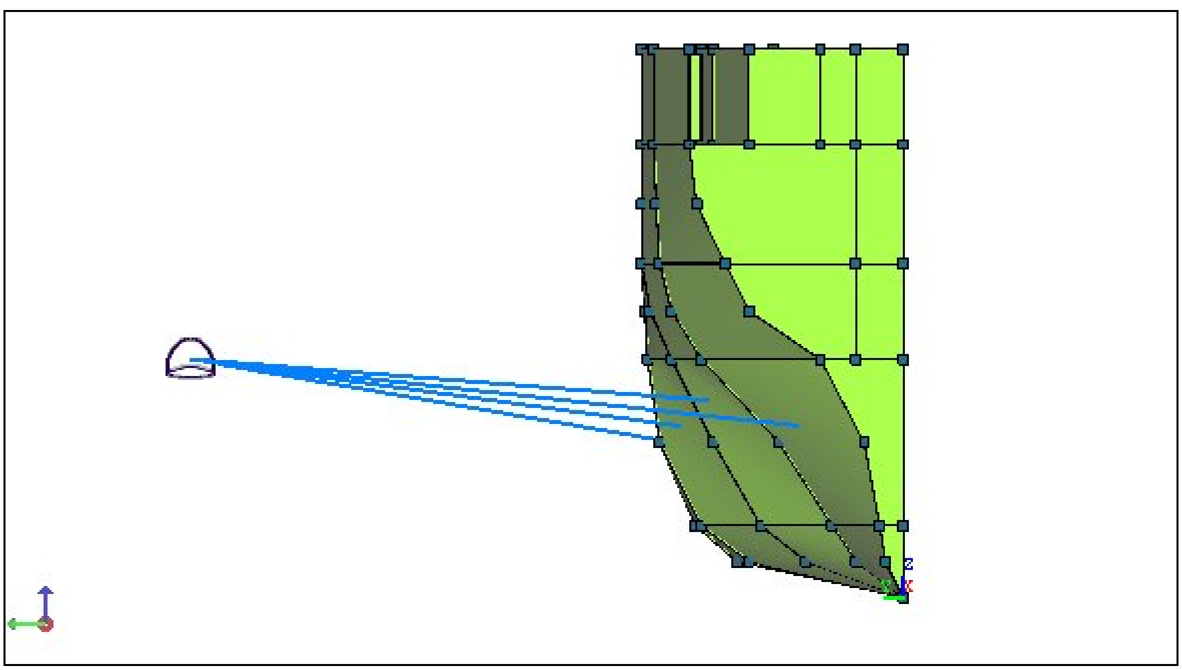

Fig.12 Location of receiver point

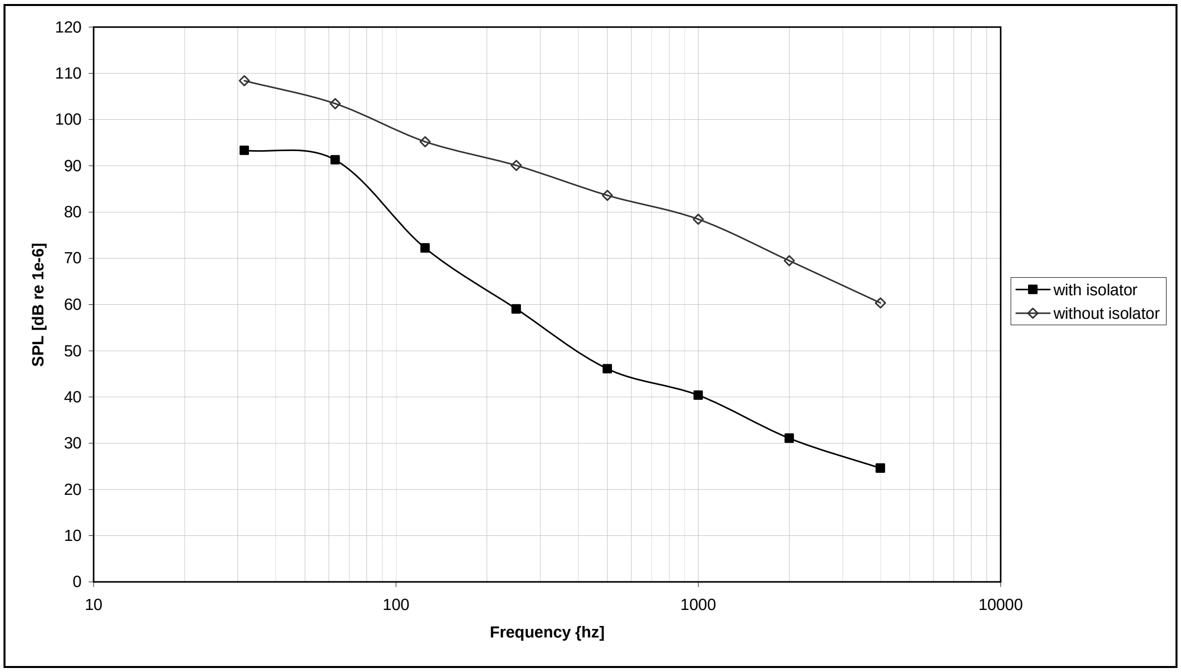

Fig.13 Sound Pressure level at distance app. 20m from ship in sea water with and without engine support isolator

On fig.15 there is a Sound Pressure Level (SPL) shown in ‘engine room’ and room above ‘engine room’. There are two variants. One with untreated engine room (absorption coefficient α=0.01) and one with treated engine room. This means that in ‘treated’ variant, engine room has an absorption coefficient according to fig.14.

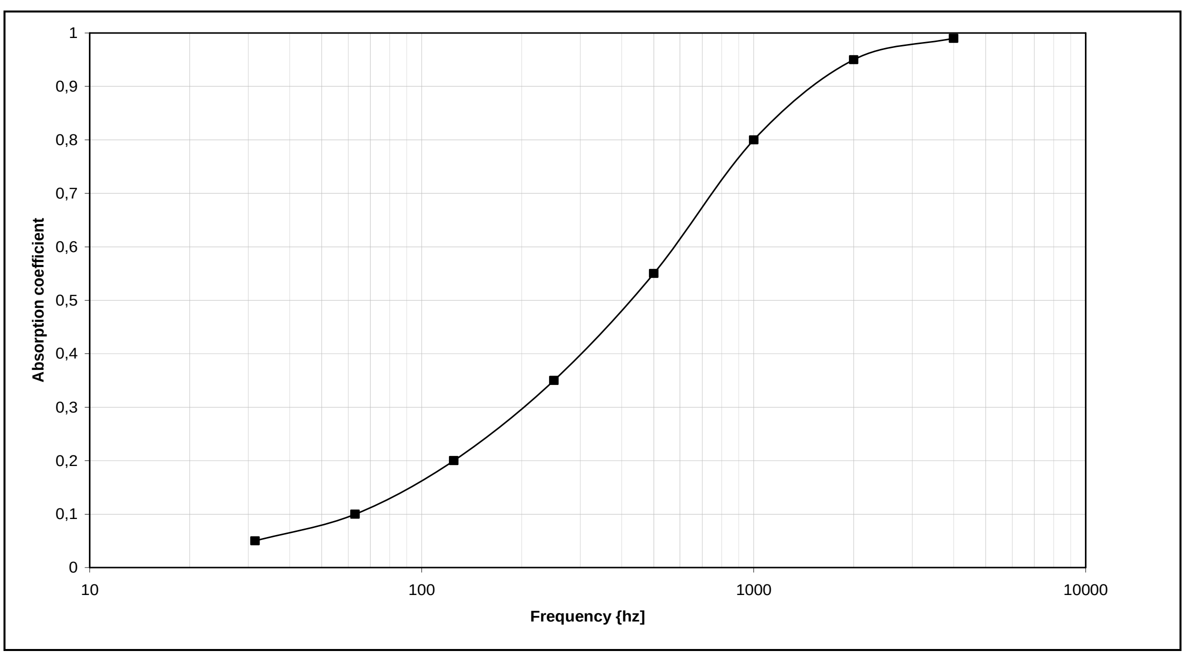

Fig.14 Absorption coefficient of ‘treated’ engine room

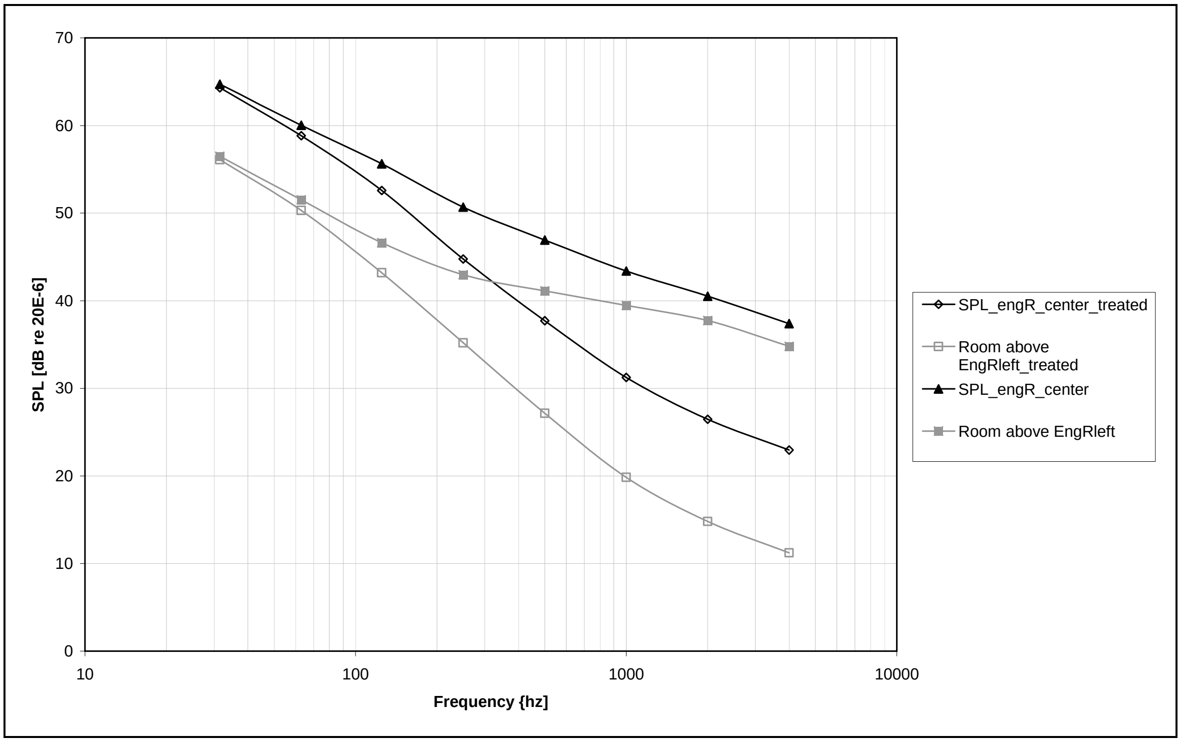

Fig.15 SPL results in engine room and room above engine room

As one can see on fig.15 there is a major improvement in noise condition especially in room above engine room. Below transfer function is shown. There are two variants as well - one with treated engine room and second with untreated engine room.

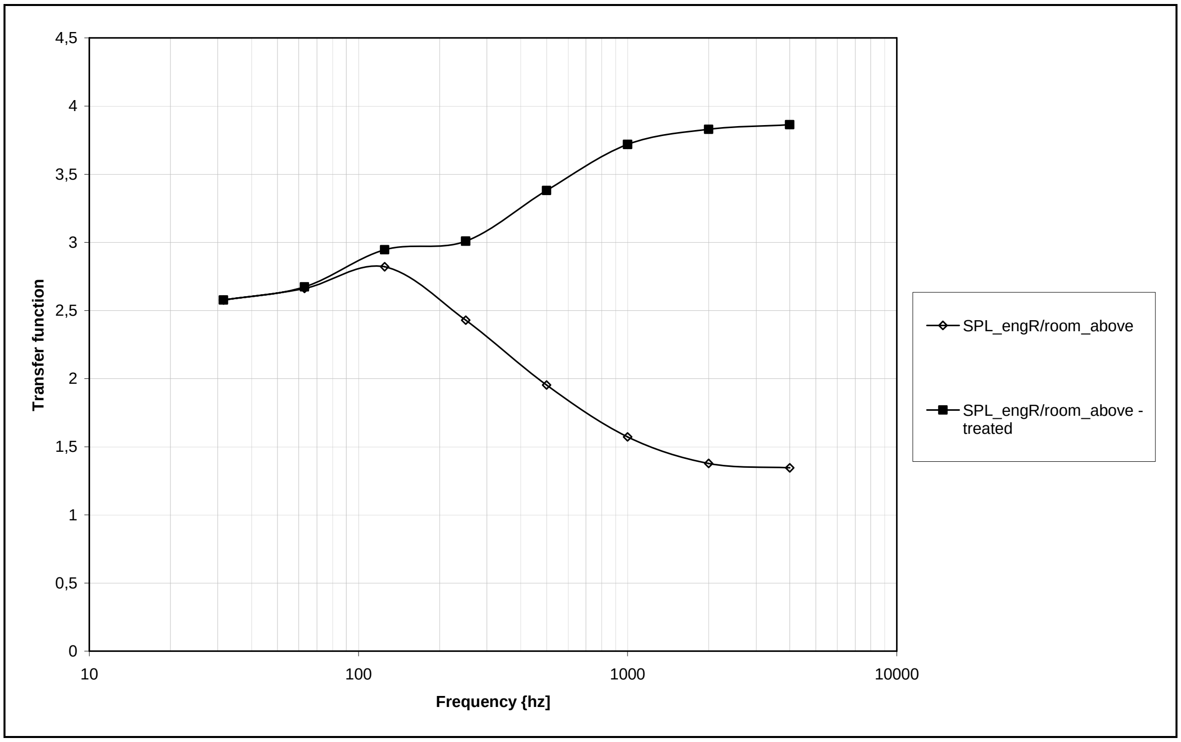

Fig.16 Transfer function

REFERENCES

[1] E. Sarradj, Energy-based vibroacoustics: SEA and beyond, 1-3, CFA/DAGA 2004.
[2] J. Wiciak, Analiza przenoszenia energii dźwięków materiałowych w złożonych układach mechanicznych na przykładzie elementów płytowych, Phd Thesis, AGH, 7-11, Kraków 1997.
[3] S. Weyna, Uniwersalna metodyka prognozowania poziomu hałasu na nowo projektowanych statkach cz.II, Politechnika Szczecińska, Szczecin 1984.
[4] AutoSEA2 User's guide, Vibro-Acoustic Sciences, 1999.
[5] www.seanet.be - BRITE/EURAM thematic network on "Statistical Energy Analysis"