SHIP ON-BOARD NOISE PROPAGATION ANALYSIS METHODS

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In last 10 years there has been a major development on anti-noise and vibration treatment materials used in shipping industry. Starting from passive elements such as mineral wool, elastic mountings up to active noise reduction systems based on real-time processors. Simultaneously ship-owners demands for silencing their ships has also evolved. Hence, noise limits got more restricted (especially when comfort class is important i.e. passenger ships, yachts, etc).
In order to fulfill those demands noise propagation analysis have to be performed. For many years wave propagation model or statistical model has been incorporated for this purpose. Statistical Energy Analysis method has been also used especially for high frequency range. However only in past few years one can analyse complete frequency spectrum using combined FEA/SEA or EFEA method. In this paper review of noise propagation method tools has been presented with given examples and new direction in research and development has been pointed.

INTRODUCTION

Ship on-board noise propagation is one of the most important issues which shipyards and ship-owners have to deal with. This issue begins during early stage of designing a new vessel or rebuilding. Noise and thermal insulation, walls, ceilings and floors are being selected in order to fulfill the noise criteria. This activity is done based on noise and vibration propagation analysis. Correct noise and vibration analysis is the only way to achieve a goal - optimized costs and noise criteria fulfillment. Noise analysis is one of the steps one has to take during a ship design - it's obvious when one take into account that outfitting costs are very high with respect to overall costs.

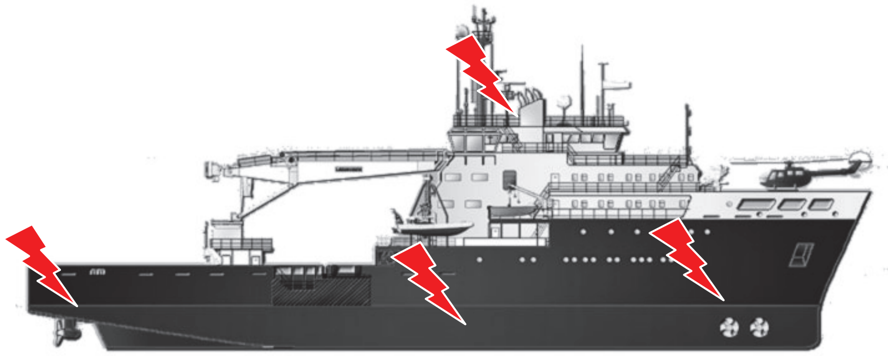

Fig.1. Multi-Function Tender with main noise sources pointed.

Ship onboard noise propagation became serious issue especially for vessels upto 100 m of a special purpose such as AHTS, PSV, etc. Rising power demands together with relative small vessel dimensions and noise limits criteria being more restricted define that one need to know exact noise propagation distribution. Moreover, the philosophy of maneuvering is changing - most of a time one uses Dynamical Positioning Systems (with thrusters and POD's working in transient modes). Therefore noise propagation distribution is different to those conventional ones (i.e. ships with superstructure placed on top of the engine room in the aft part of the ship). Additionally noise policy is getting more strict. Noise level limits established in 70's have changed lately and almost every Classification Society have presented their own recommendations in this area. Therefore in order to fulfill those requirements during design stage one has to incorporate proper noise propagation analysis method.

Classification Societies recommend Statistical Energy Analysis (SEA) noise prediction method for ship's high noise requirements. This method is also recommended at the time of an advanced design that is in a situation when one has a sufficient number of input data. In the absence of such data problem of reliability of the results raises. In this case, the measurement data will be applied to certain standard structures.

There is a growing trend in orders for accurate vibroacoustic analysis of a floating objects. classic methods used to predict the noise have a maximum of about 75% accuracy of the later measurements. In the case of stricter standards, for ship-owners and shipyards such accuracy is not sufficient (yards often have to pay penalties for exceeding the measured noise levels). It is therefore necessary to meet market expectations and develop methods for prediction of noise propagation in the floating objects.

1. NOISE PROPAGATION IN SHIP STRUCTURE

From the acoustical point of view ship is a very difficult object to analyse. It is a rigid structure with many noise sources, flanking paths, discontinuities etc.
As far as ship is concerned, noise in compartment is a result of different kind of equipment and machinery noise influence. These noise sources are commonly located in aft part of the

ship (i.e. ro-ro ship) or in the midship part (i.e. ferry), which affects all compartments. The most important noise sources on a ship are:

➲ *main engine and generator sets*
➲ *gearboxes*
➲ *propellers (cavitation effect)*
➲ *exhaust systems with engine room ventilation*
➲ *auxiliary mechanism such as hydraulic systems, pumps*
➲ *ventilation and air-conditioning systems*
➲ *side thrusters*

Participation of particular noise source on total noise in analysed compartment depends on a ship structure, power and structure of mechanisms, their foundation, distance between noise source and analyzed compartment. In compartments, where noise sources are installed in (i.e. engine room, pump room, bow thrusters room), the most influence on total noise is a machinery **air-borne noise** (noise which is fundamentally transmitted by way of the air). In compartments that are located at some distance from noise sources, **structure-borne noise** (noise which is generated by vibrations induced in the structure - these vibrations excite partitions in ship structure and cause them to radiate noise) dominates.

Generally, noise present on a 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. 2). [1]

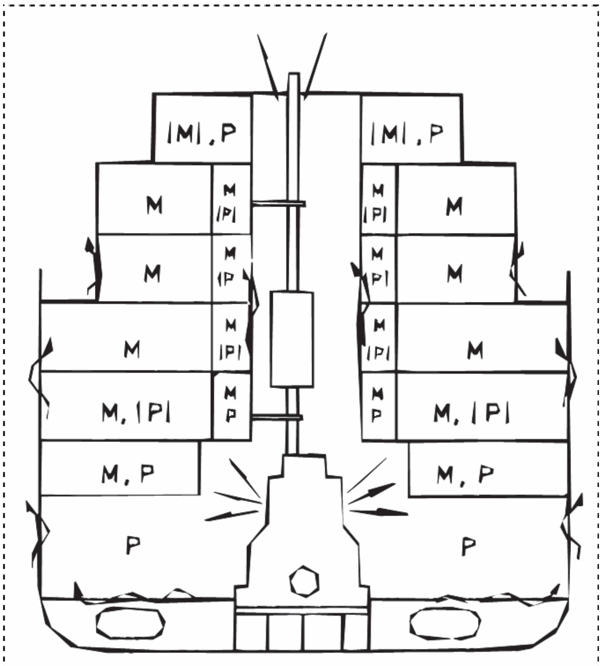

Fig.2. Structure-borne (M) and air-borne (P) noise influence on compartments.

2. STATISTICAL ENERGY ANALYSIS

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 have 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 application where SEA was used, there are four major:

- cars
- trains
- ships and offshore structures
- aeroplanes

Considering one single subsystem, any excitation acting on this subsystem can be characterized by the resulting power input P_i into subsystem (fig.3). 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:

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

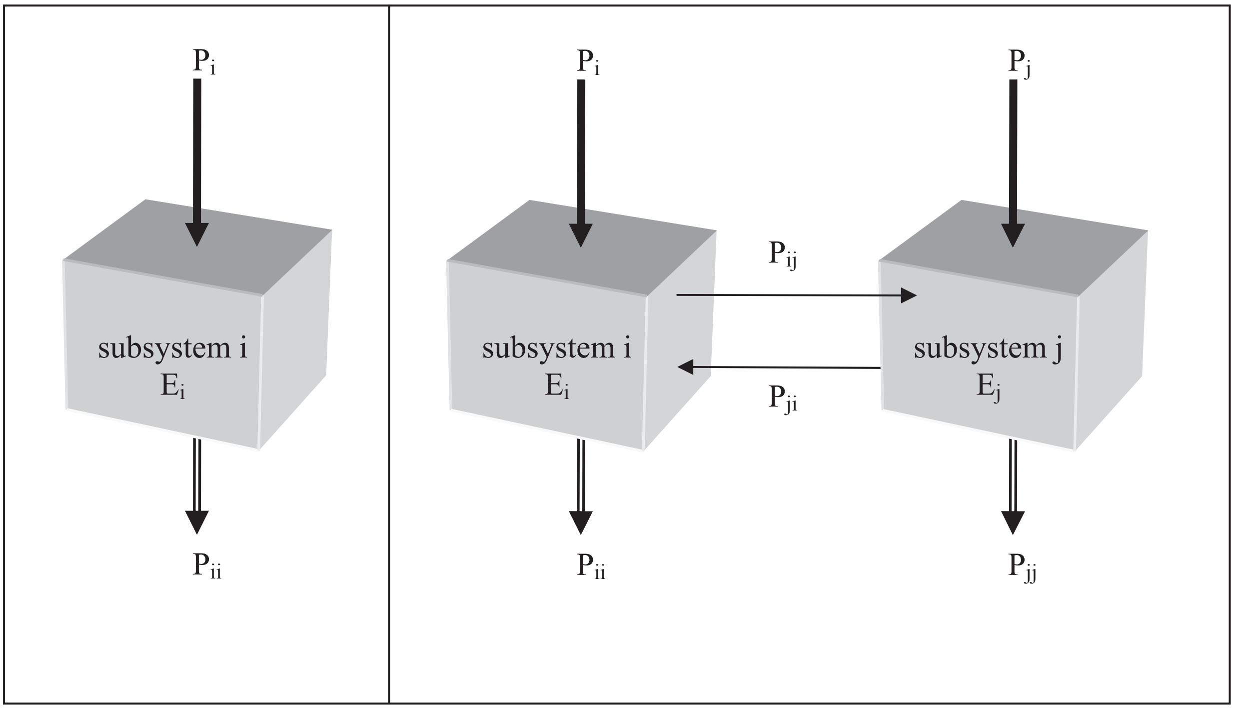

Fig.3. Single subsystem (left) and coupled subsystems (right).

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.3), 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 andpower 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.4). 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:

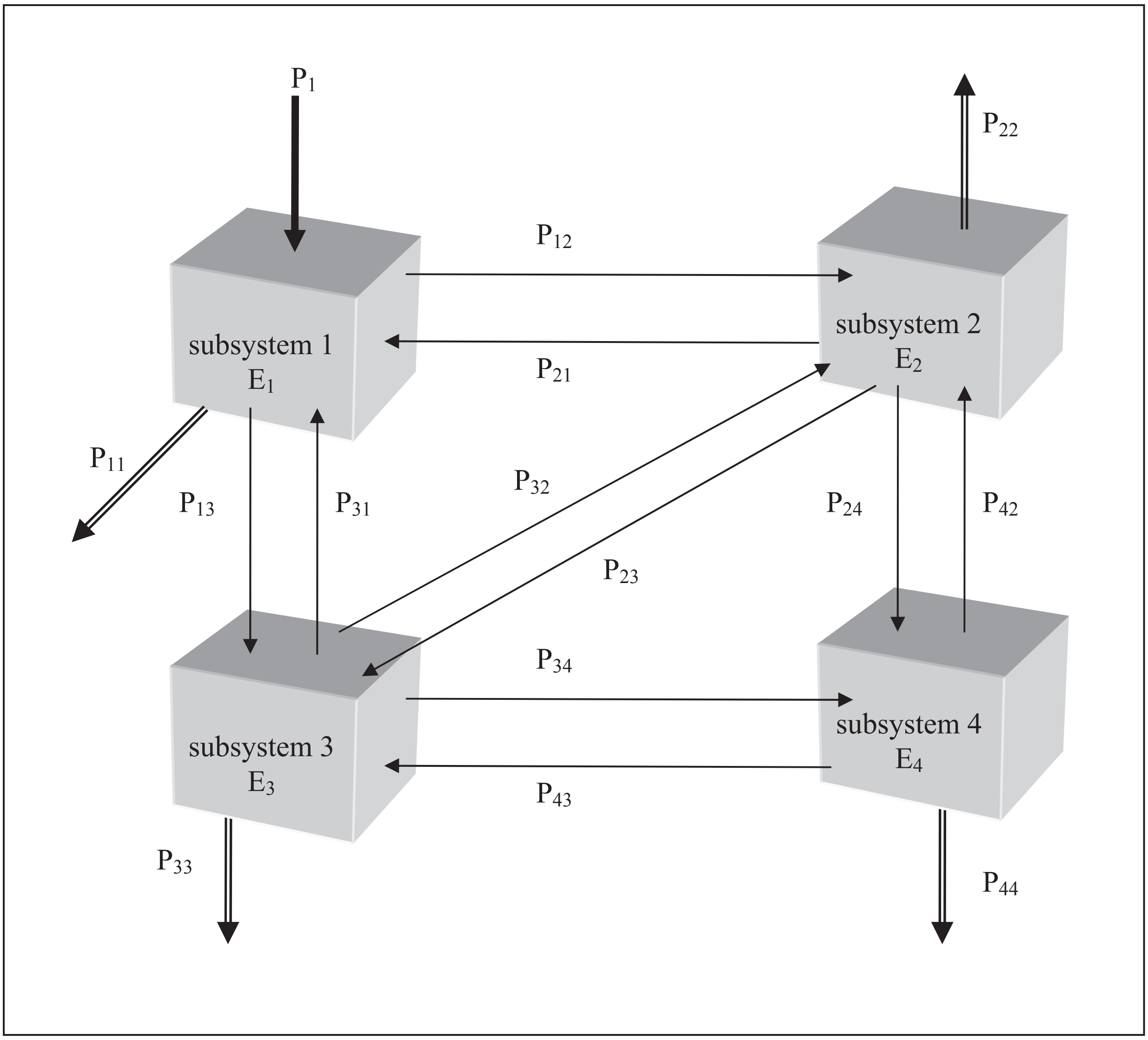

Fig.4. Four subsystems.

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

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

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

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

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

$$\omega \cdot \begin{pmatrix} \eta_{11} & -\eta_{21} & -\eta_{31} & -\eta_{41} \\ -\eta_{12} & \eta_{22} & -\eta_{32} & -\eta_{42} \\ -\eta_{13} & -\eta_{23} & \eta_{33} & -\eta_{43} \\ -\eta_{14} & -\eta_{24} & -\eta_{34} & \eta_{44} \end{pmatrix} \cdot \begin{pmatrix} E_1 \\ E_2 \\ E_3 \\ E_4 \end{pmatrix} = \begin{pmatrix} P_1 \\ 0 \\ 0 \\ 0 \end{pmatrix} \tag{7}$$

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:

$$\eta_{ii} = \eta_i + \sum_{j,j \neq i} n_{ij} \tag{8}$$

3. NEW METHODS FOR NOISE ANALYSIS

One of the biggest disadvantages of SEA method is its inaccuracy in low frequency (for ship structures upto 150 Hz). Also in design practice one build a numerical model for vibration analysis using FEM code and other model for noise propagation. This takes a lot of time. Method developed in 90's called Energy Finite Element Analysis (EFEA) can overcome those issues.

Statistical Energy Analysis (SEA) and Energy Finite Element Analysis (EFEA) are two methods to evaluate vibration/noise spreading from a source in a complex structure. The common word in these names is 'energy'. The core parameter, which these methods are able to determine, is energy density (energy per unit area or volume). Energy density is proportional to vibrational velocity squared. In both methods energy density is averaged over time and usually averaged through frequency band.

The controlling equation in both methods is a formulation of energy balance within and between subsystems, which together define a system. If, for example, the subject of interest is a ship, then a subsystem (or element) may be a part of hull structure such as bulkhead or deck section. The individual modes of vibration are not considered in the energy balance methods. In this sense both methods are statistical.

The principle difference between the two methods is the energy balance formulation for each element. For SEA it is assumed that energy density does not depend on coordinates inside an element. Physically this means that there is a diffusive field for each element. Energy balance in this case is expressed mathematically as a linear algebraic equation that equates the energy going in and out of each element. Energy density is unknown in this equation. The number of equations is equal to number of each element. The combination of all equations produces a system of the linear algebraic equations, which has one solution for each set of energy inputs.

For EFEA, energy balance is formulated for differential (elementary) parts of an element. Mathematically, it leads to a second order partial differential equation relative to energy density (the unknown in this equation) for each connected element. An analytical solution for partial differential equation is not practical. Numerical methods provide a feasible solution.

SEA requires fewer computing resources than EFEA, if the average energy of a subsystem is the subject of interest. However, EFEA may provide a level of detail, which is not achievable for SEA. [2]

The biggest EFEA advantages are:

- Finite element based model (ease of creating the model; Multi-discipline Design - fig.5)

- No modal density information is needed
- Space dependent acoustic treatment & structural damping
- Spatial variation in the results

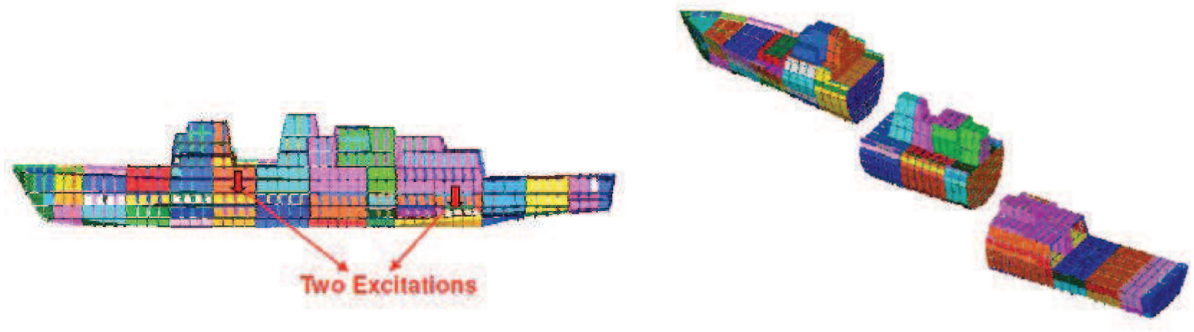

Fig.5. EFEA model with natural bulkhead division [3].

4. CONCLUSION

As one can see there has been rapid development of hybrid methods in last 10 years. This is mostly an effect of multi-design process development. During ship design process it is vital to define all major noise paths and verify their impact on overall noise level. This is a very important issue especially for special purpose vessels such as AHTS, PSV with their raising power demands. One should take also into consideration that EFEA is a new method and does not have a long history with ship acoustics problems whereas SEA is used in commercially available programs and has been validated for problems in the marine field.

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