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FEASIBILITY OF EXPERIMENTAL DETERMINATION OF SEA DAMPING LOSS FACTORS OF SUBMARINE STRUCTURES

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ABSTRACT
Statistical Energy Analysis is a useful technique to predict at the design stage average noise and vibration levels on ships or submarines, in particular self noise levels on sonar arrays due to machinery on-board noise or flow noise. In order to achieve accurate predictions, it is necessary to introduce realistic damping loss factors in the models. For that purpose, an experiment was conducted on a specific facility whose structure is representative of a piece of submarine hull. Damping loss factors and other parameters of portions of the hull and of some connected structures have been obtained along frequency up to several kHz, using excitation either with a shaker or a hammer, the second method being quicker to operate. The results have shown consistency of the data and confirm the feasibility of the technique, even for thick structures as those used on ships or submarine.

1 - INTRODUCTION
To assess the feasibility of experimental SEA on real submarine structures, an experiment has been conducted on a specific facility. Previous studies on that topic dealt with reduced scale structures [1].
The facility " Téthys ", available in DCN Cherbourg, is devoted to noise control studies on submarine structures and equipments. The side view of the test structure is shown on figure 1. The external hull is periodically ribbed in the crosswise direction and the thickness is 32 mm. The internal arrangement consists in three compartments containing test machinery and related pipe and electrical networks, separated by bulkheads 1 and 2 (with respective thicknesses 38 mm and 6 mm). The facility is moored in a dock, and the waterline is located about 1 meter under the upper deck. For the analysis, the system under consideration is the central section, limited by the hull, the two bulkheads, and the roof.

2 - EXPERIMENT
The " AutoSEA " model used for the analysis of the results is shown on figure 2. An adequate choice of subsystems must be such as $\eta_{ij} \ll \eta_i$ (i.e. the coupling loss factors must be significantly lower than the damping loss factors). Problems may arise at low frequencies due to the coupling with connected structures that are not included in the model (in particular the front and rear hull sections).
The model adopted here includes 7 subsystems: the two bulkheads, the compartment (air acoustic cavity) and 4 hull sections. The hull is divided into left and right sides, themselves divided into two parts (lower part in contact with seawater, upper part in air). The latter decomposition is justified by the change of the external fluid (added mass and radiation).
The SEA method requires performing for each subsystem an average over excitation points and measurement points. The quantities to be evaluated are the energies of the subsystems for a set of input powers. For that purpose, grids of both excitation and measurement points were defined. The number of excitation points was set to 6, in order to limit the data volume. The acquisition system included a portable PC, an acquisition interface and signal conditioning, with 8 analog inputs being simultaneously recorded and the AutoSEA-X software handling the SEA experimental analysis. The experiment was

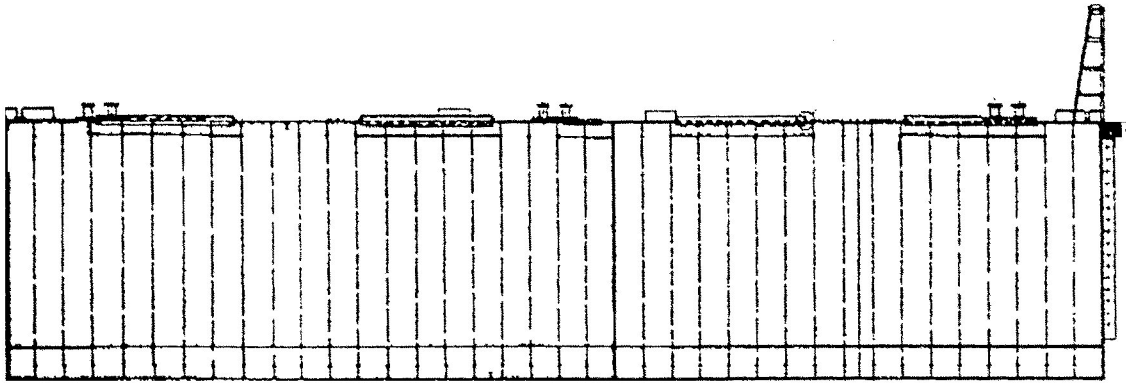

Figure 1: The test structure " Téthys " in DCN Cherbourg.

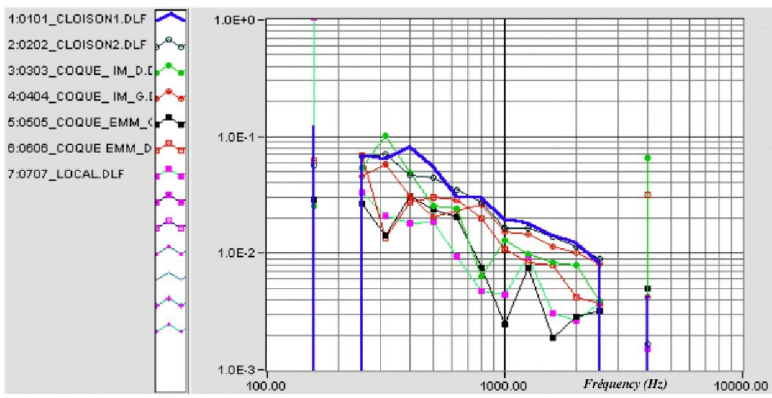

Figure 2: The " AutoSEA " model of " Téthys ".

conducted with the help of the noise & vibration team of DCN Cherbourg. The frequency range of interest lies between 100 Hz and 10 kHz.
For the excitation, two techniques were checked:

- Excitation with a shaker: The shaker was fitted with a force sensor, and an accelerometer was located close to the input point. The acceleration was measured within the different subsystems by displacing some accelerometers when required.
- Excitation with a hammer: The hammer was fitted with a force sensor, and the acceleration at the input point was measured as previously. Here, the reciprocity principle could be applied, i.e. the measurement accelerometers were located at the 6 excitation points of the previous shaker technique, and the hammer was displaced for each previous observation point.

In the case of the internal compartment, the same procedure as for the shaker is used, but the excitation was generated with a loudspeaker and the evaluation of the energy by moving a microphone at various locations.
Appropriate averages were made over the transfer function data samples, before applying the process (average per subsystems and per one third octave band).

3 - DETERMINATION OF SEA PARAMETERS
For a given frequency band, the energy balance of the total system writes [2]:

$$\frac{\Pi_i}{\omega_0 \left|F_i\right|^2} = \sum_{j=1}^{N} \eta_j C_{ji} \tag{1}$$

Π_i is the input power in subsystem i, ω_0 is the central frequency and η_j the damping loss factor in the different subsystems ($1 \leq j \leq N$). C_{ji} is defined as the energy of subsystem number j when subsystem number i is excited. If each subsystem has been excited in turn through N successive experiments, we obtain then the following system of linear equations:

$$\begin{bmatrix} \dfrac{\Pi_1}{\omega_0 \left|F_1\right|^2} \\ \dfrac{\Pi_i}{\omega_0 \left|F_i\right|^2} \\ \dfrac{\Pi_N}{\omega_0 \left|F_N\right|^2} \end{bmatrix} = \begin{bmatrix} C_{11} & C_{i1} & C_{N1} \\ C_{1i} & C_{ii} & C_{Ni} \\ C_{1N} & C_{iN} & C_{NN} \end{bmatrix} \begin{bmatrix} \eta_1 \\ \eta_i \\ \eta_N \end{bmatrix} \tag{2}$$

Solving (2) gives the unknown damping loss factors. In some cases, negative values may be obtained, which have no physical meaning. If this occurs, the choice of subsystems is not appropriate, or the quality of measurements should be checked (in particular the injected powers). The validity of the experimental results is determined by computing a variance using a Monte-Carlo technique (random variation on the energies and injected powers) [4]. To convert the measured transfer velocities into energies, an experimental determination of the equivalent mass of a subsystem is automatically processed. This is achieved using the time evolution of the energy (reverberation time). The experimental modal densities can also be derived from mobility measurements.

The coupling loss factors can be obtained by solving a linear system of size $N \times N$. A specific condensation technique allows to reducing it to N systems of smaller size. However, this approach can sometimes lead to some negative coupling loss factors. In our case, with regard to the complexity of the structures, a simplified approach is used. It leads to the expression:

$$\eta_{ij} = \frac{1}{\omega_0} \frac{C_{ij}}{C_{ii}} \frac{\Pi_j}{C_{jj} \left|F_j\right|^2} \tag{3}$$

These different parameters can be compared with theoretical SEA for consistency.

4 - RESULTS

From the two excitation techniques, the experimental equivalent masses, modal densities, damping and coupling loss factors have been determined. Figures 3 and 4 show respectively the estimated damping loss factors of the subsystems for respectively the shaker and the hammer, computed using the experimental equivalent masses for velocity to energy conversion. In the overall, the results are consistent. In the first case, the results are valid in the range 250 Hz − 2500 Hz, and in the second case in the range 200 Hz − 3150 Hz. The frequency limitations are most often due to the instrumentation characteristics, leading to poor signal to noise ratio in some frequency bands. Better accuracy could also be obtained by increasing the number of measurement points. The values of damping loss factors are in general in the range 0.01 to 0.1, decreasing along with frequency. For the structures in contact with seawater, part of the damping may be due to acoustic radiation.

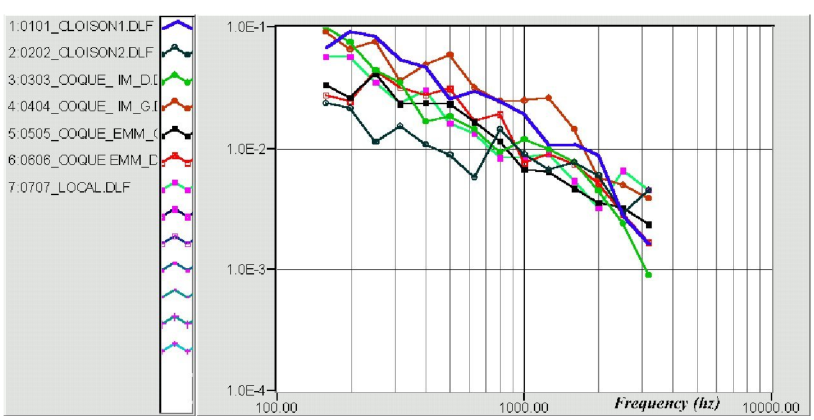

Figure 3: Experimental damping loss factors using excitation by a shaker.

5 - CONCLUSIONS

An experiment has been conducted on a specific facility to determine the feasibility of experimental Statistical Energy Analysis on submarine structures. Consistent results were obtained for the damping

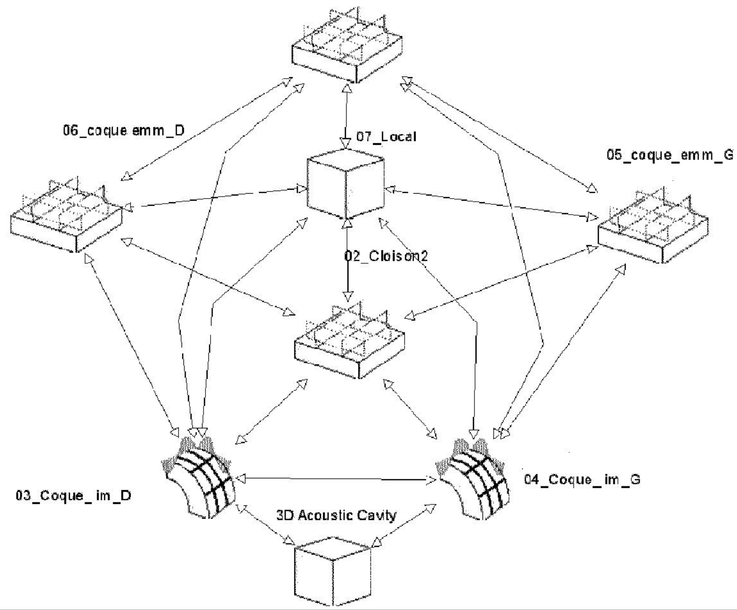

Figure 4: Experimental damping loss factors using excitation by a hammer.

loss factors and other parameters, in the frequency range 200 Hz − 3000 Hz. Two experimental procedures have been tested: one using a shaker, the other using a hammer and the reciprocity principle. The second technique is recommended because the results are satisfactory and it is much faster to operate than the first one (0.5 day instead of 3.5 days in the present case).

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