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DAMPING AND COUPLING LOSS FACTORS ESTIMATION IN SEA METHOD; WHAT IS REALLY MEASURED?

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1. INTRODUCTION

The inversion of the Energy Matrix E of the SEA equation $P = \eta\varpi E$ gives Damping Loss Factors (DLF) and Coupling Loss Factors (CLF) of a vibrating structure [1]. The Matrix inversion is very sensitive to small variations of the input variables i.e. the mean power input P and the statistical mean energy E. The result of CLF and DLF computation is then only an estimate of the actual.

We propose a method to surround this estimate based on a standard deviation computation which gives a confidence interval for the CLF and DLF calculated values.

Through a simple theoretical case with 3 coupled sub-systems both in a weak and strong coupling situation, it is shown that this standard deviation estimate is a very useful information in experimental SEA analysis.

2. TEST CASE DESCRIPTION

With help of AutoSEA software [2], we design a 3 sub-systems structure made of 3 flexural coupled aluminium plates of same dimensions (0.7m x 0.7m). Plate 1 is coupled with plate 2 and plate 2 is coupled with plate 3. Two configurations are considered :

- first, the plates are mechanically coupled along their width. The internal damping is constant and is set to 0.01 for all 3 plates. The corresponding masses are :
    - Plate 1 : 1.32 kg
    - Plate2 : 2.65 kg
    - Plate 3 : 3.97 kg

- second, the plates are coupled by points (5 connection points between Plate 1 and Plate 2 and 3 connection points between Plate 2 and Plate 3). In this case, the masses are 0.66kg for Plate 1, 10.56kg for Plate 2, 39.6kg for Plate3 and the internal damping is set to 0.01 for Plate 1, 0.1 for Plate 2 and 0.06 for Plate 3.

The first configuration represents a strong energetic coupling between the plates and the second configuration a weak energetic coupling (at least weaker).
These two SEA networks are solved with AutoSEA to get all useful SEA parameters for each configuration (injected powers, average velocities, coupling loss factors, modal energies). These parameters will be used for our demonstration.

3. COMPUTATION PRINCIPLES

Reverse (or Experimental) SEA consists in CLF and DLF determination from injected power and average velocities measurements. Measurements are supposed to give the present energy and power input level of each sub-system through a discrete sampling of the vibrating field. In practice, only an estimate of energy and power can be achieved. Then without any criteria for estimating the measurement quality, it is difficult to get confidence in CLF and DLF computation.
One proposes a method to estimate the confidence interval of all measured and computed parameters in the Reverse SEA process. This method is divided in 3 steps:

- The standard deviation of input power measurements is first computed and gives the valid result frequency range associated with the power injected method.

A standard deviation for velocities measurements is computed in two ways. A point to point standard deviation is first derived which corresponds to the spatial diffuseness in the system and a second pseudo-standard deviation is computed by selecting a subset of M accelerometers among all N available on the sub-system under analysis. One evaluates a dispersion coefficient as:

$$\alpha = \sqrt{\frac{1}{K-1} \cdot \sum_{i=1}^{K} (< V(i)^2 >_M - < V^2 >_N)^2}$$

where K is the number of groups of M accelerometers among N.

One obtains then a more realistic velocity dispersion estimation.

- The third step consists in a perturbation of the matrix parameters before inversion using a Monte-Carlo approach. The matrix coefficients are determined using perturbation of input power and energy around their mean value and within their standard deviations following a gaussian or uniform probability distribution.

Finally, one gets CLF and DLF values with a confidence interval which is expressed in dB around the mean value.

4. METHOD FOR PERTURBATION ANALYSIS

The effect of noise in input data on CLF and DLF computation (simulated by a matrix parameters perturbation) is demonstrated using the following method:
one starts from the injected power and velocity values derived from the two previous SEA models. From this data base, CLF and DLF are computed with different degrees of perturbation .
3 cases are investigated: dispersion of 0.5 dB on injected power and velocity values then 1dB and 2dB and comparisons of results with theoretical results from AutoSEA.
Let us note that without perturbation, Reverse SEA gives exactly the same results than the original computed CLF and DLF. All Reverse SEA computations are performed using ASEI Software [3].

5. EFFECT OF PERTURBATION ON CLF AND DLF

The CLF from Plate1 to Plate 2 and Plate 2 to Plate 3 are presented on the Figures 1 and 2 respectively for the weak coupling and strong coupling cases with 0.5dB perturbation in input data.
In the weak coupling case (Figure 1), a 0.5dB perturbation on the matrix parameters does not modify the prediction of CLF. The same result is obtained with DLF computation.

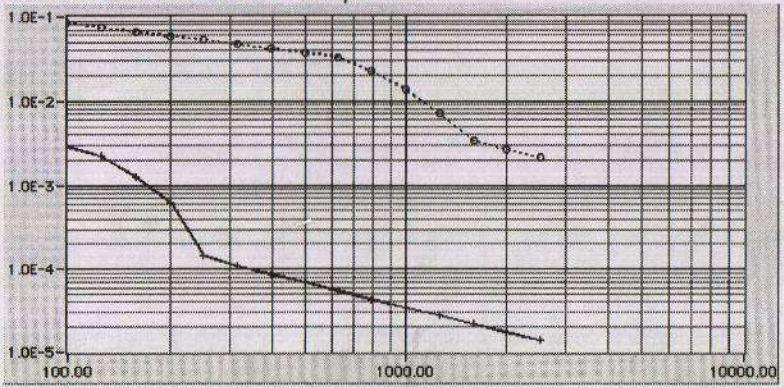

Figure 1 : Weak coupling case- 0.5dB perturbation
CLF from Plate 1 to Plate 2
(ASEI : continuous line, AutoSEA : continuous line and '+').
CLF from Plate 2 to Plate 3
(ASEI: dotted line, AutoSEA: dotted line and 'o').

Results in the strong coupling case (Figure 2) show some differences compared to AutoSEA prediction (without perturbation) but the error is small on average. On the other hand, standard deviations on CLF and DLF, show great differences between strong and weak coupling cases (Figure 3).

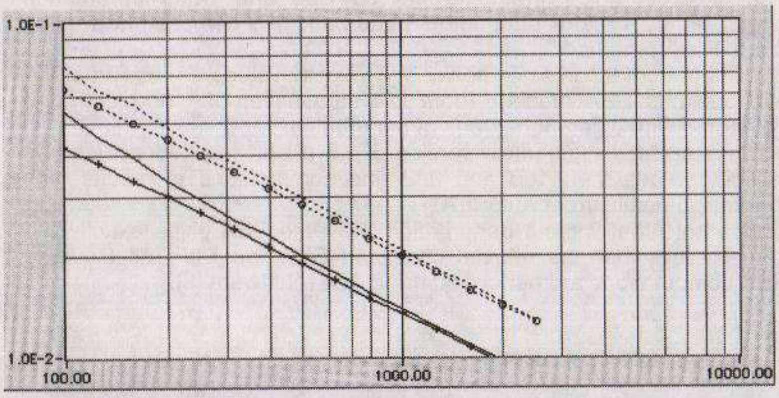

Figure 2 : Strong coupling case
CLF from Plate 1 to Plate 2
(ASEI : continuous line, AutoSEA : continuous line and '+').
CLF from Plate 2 to Plate 3
(ASEI: dotted line, AutoSEA: dotted line and 'o').

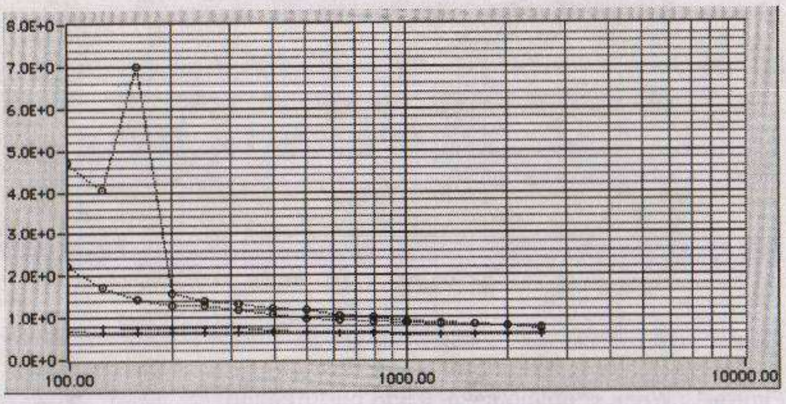

Figure 3 : Comparison between standard deviation (in dB) on CLF in weak coupling situation (-+-) and in strong coupling situation (-o-).

These standard deviation differences can be explained from modal energy behaviour in the SEA models. The observation of the modal energies in the strong coupling model shows that the modal energy steps in dB between the 3 plates is lower than the perturbation applied to the matrix parameters.
As the power flow between sub-systems is governed by the difference between modal energies, the applied random perturbation can randomly invert this power flow and SEA equations are no more verified in that cases. On average, the CLF and DLF computed values are near from the theoretical ones but the confidence level is decreasing. The worst situation is achieved at low frequencies where the energy of the different sub systems are near from equirepartition. In the weak coupling case, the modal energy steps between plates is greater than the perturbation leading to a good CLF-DLF prediction (1dB confidence level).

To confirm the previous explanation, if the perturbation factor is set to 0.1dB, one gets the right results in terms of standard deviation and value for CLF and DLF in the strong coupling case.

The computed Plate2 to Plate 1 CLF (strong coupling case) is presented on Figure 4 for different perturbation factors.

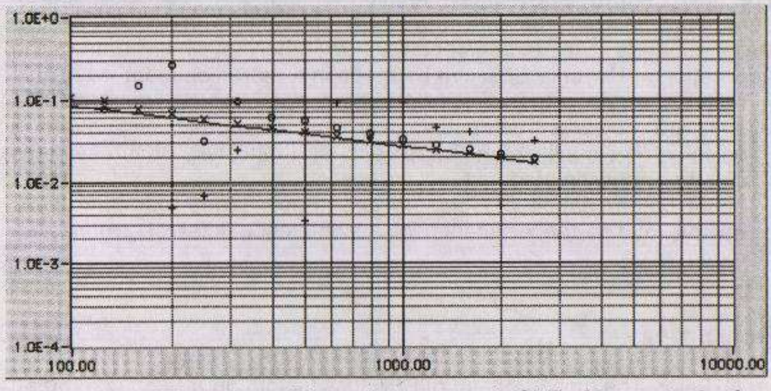

Figure 4 : Plate 2 to Plate 1 computed CLF. No perturbation (continuous line), 0.5dB perturbation (x x), 1 dB perturbation (o o), 2dB perturbation (+ +)- strong coupling case

With 1dB of dispersion on average velocities and injected powers which seems to be experimentally a limit in term of accuracy, one gets some important fluctuations of the CLF coefficient. More than 1 dB of dispersion gives negative CLF due to an ill-conditioned matrix during random inversion. Interpolation of these curves can approach physical reality but without knowledge of the associated standard deviation one can misinterpret the output data.

One can state that:

- if the standard deviation on injected power and average velocities is high (biased or noisy measurements), the CLF and DLF computation will be hazardous if the modal energies steps between sub-systems are lower than these standard deviations.

- during experimentation, when sub-systems are not well-known, the standard deviation is an indicator for improving the test data base. When measuring, if standard deviations on injected power and average velocities stay in reasonable limits (less than 1dB) but come to high value on CLF-DLF it points to possible strong coupling between sub-systems.

6. CONCLUSIONS

We have shown that the computation of standard deviation for all parameters which govern the SEA equation provides helpful information to the experimentalists to analyse their data. The application of Reverse SEA can be made in a more confident way :

- better analysis of measurements input data through experimental standard deviation computation of injected power and average velocity . The quality of measurements and diffusivity of sub-systems can then be estimated.
- better determination of Coupling Loss Factors and Damping Loss Factors due to the estimation of a confidence interval around the mean value.

References

[1] N. Lalor, The measurement of SEA loss factors on a fully assembled structures, ISVR Technical Memorandum n°150, August 1987.

[2] AutoSEA Software developed by Vibro-Acoustic Sciences, Inc., 5355 Mira Sorrento Pl#100, San Diego CA 92121.

[3] ASEI Software developed by InterAC, 1, Impasse des Hirondelles, 31240 L'union, France.