Vibration and sound radiation of a double-plate system

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1. Introduction

Most ship structures can be regarded as a radiating envelope (hull) connected at the vibrating internal structures through the vibration isolators. A simplified analysis of the problem may be done by considering two parallel elastic plates connected through four suspensions. This communication deals with the vibrations of a combined system and the sound radiation of the bottom plate when the top plate becomes excited by a point force in low- and mid-frequency ranges. In order to reduce the size of the linear system to be solved, the structure is divided into six sub-structures which are the two plates and the four suspensions and for which mechanical impedances must be determined. The mechanical impedances of both plates were obtained from a variational method general enough to include arbitrary boundary conditions, point-masses and stiffeners on either plate. The mechanical impedances of the suspensions were calculated with a four-pole network approach. The model is used to investigate the efficiency of suspensions and the effect of structural changes on either plate in order to minimize the radiated power.

2. Theoretical approach

The studied system consists of two thin plates connected through four suspensions which include a spring and a dashpot. The top plate (internal structure) is excited by a mechanical force F_1 and the bottom plate (external radiating structure) is located in an infinite baffle and is surrounded by a semi-infinite medium of low density. Each of these two plates may have any type of boundary conditions. More details on the theoretical calculation are given in [1].

The complete system can be subdivided into six sub-elements (two plates, four suspensions) which permits us to reduce the dimensions of the system to be solved and has the advantage of giving the force transmissibility through the suspension directly.

If $F_i^{(1)}$ is the force applied to the suspension i by the top plate and $F_i^{(2)}$ is the force applied to the bottom plate by the suspension i, one obtains the following relations for the velocity of each plate at the junctions, where the cross mechanical impedance $Z_{ij}^{(k)}$ may be obtained from [1].

$$v_j^{(1)} = \frac{F_1}{Z_{1j}^{(1)}} - \sum_{i=2}^{5} \frac{F_i^{(1)}}{Z_{ij}^{(1)}} \qquad j = 2, \ldots 5 \qquad (1)$$

$$v_j^{(2)} = \sum_{i=2}^{5} \frac{F_i^{(2)}}{Z_{ij}^{(2)}} \qquad j = 2, \ldots 5 \qquad (2)$$

$$\begin{Bmatrix} F_i^{(1)} \\ v_i^{(1)} \end{Bmatrix} = \begin{bmatrix} A_i B_i \\ C_i D_i \end{bmatrix} \begin{Bmatrix} F_i^{(2)} \\ v_i^{(2)} \end{Bmatrix} \qquad (3)$$

The terms A_i, B_i, C_i and D_i are the four-pole parameters representing suspension i which can be a simple spring and dashpot in parallel or a more complex system of springs and dashpots. The relations (1), (2) and (3) gives a system of 16 linear equations with 16 unknowns $F_i^{(1)}$, $V_i^{(1)}$, $F_i^{(2)}$, $V_i^{(2)}$. For example with a spring dashpot system the values of the matrix coefficient are the following:

$$A_i = D_i = 1; B_i = 0; C_i = \left(\frac{k}{j\omega} + c \right)^{-1}$$

where ω is the pulsation, k is the spring stiffness, c is the damping coefficient.

The dynamic response of the two plates is obtained by calculating the extremum of the Hamilton functional of each plate in vacuo. The acoustic radiation of the bottom plate is obtained by the double spatial Fourier transformation of the velocity profile of that plate. Details can be found in [2].

3. Results

The results are presented in Figure 1 for two steel plates (size 0.45 m x 0,37 m x 1 mm) connected through four springs symmetrically distributed. The top plate is guided and excited by a 1N force at its centre; the bottom plate is simply supported. Figure 1 shows the effect of stiffeners added either on the upper or lower plate. The interesting parameters, as a function of frequency, are the force transmissibility (Fig. 1a) the quadratic velocity Fig. 1b) the radiation efficiency (Fig. 1c) and the radiated power (Fig. 1d).

The solid line shows the case without stiffeners. The dotted and dashed lines are the cases with four stiffeners added on the bottom and the top plates, respectively. It is worth noting the complex vibratory and acoustic behaviours of the system. In particular one can note that the addition of stiffeners decreases the structural vibration level, as expected, but increases the radiation efficiency. Both contrary phenomena lead to almost no change on the overall radiated power at medium and high frequencies.

4. Conclusions

Scientifically speaking, this new approach allows one to quantitatively predict the complex vibro-acoustic behaviour of a typical suspension system. The benefit of using an analytical method is quite obvious in terms of physical interpretation, as well as parametric study. Technically speaking it opens the door to new tools for minimizing radiated noise.

5. Acknowledgements

6. Bibliography

[1] A. Berry, J.-L. Guyader, J. Nicolas, "A general formulation for the sound radiation from rectangular, baffled plates with arbitrary boundary conditions, J.A.S.A., 88(6), 1990.
[2] A. Berry, J. Nicolas, "Acoustic radiation from a coupled planar structure", Contract report, DREA LR 91/425, March 1991.
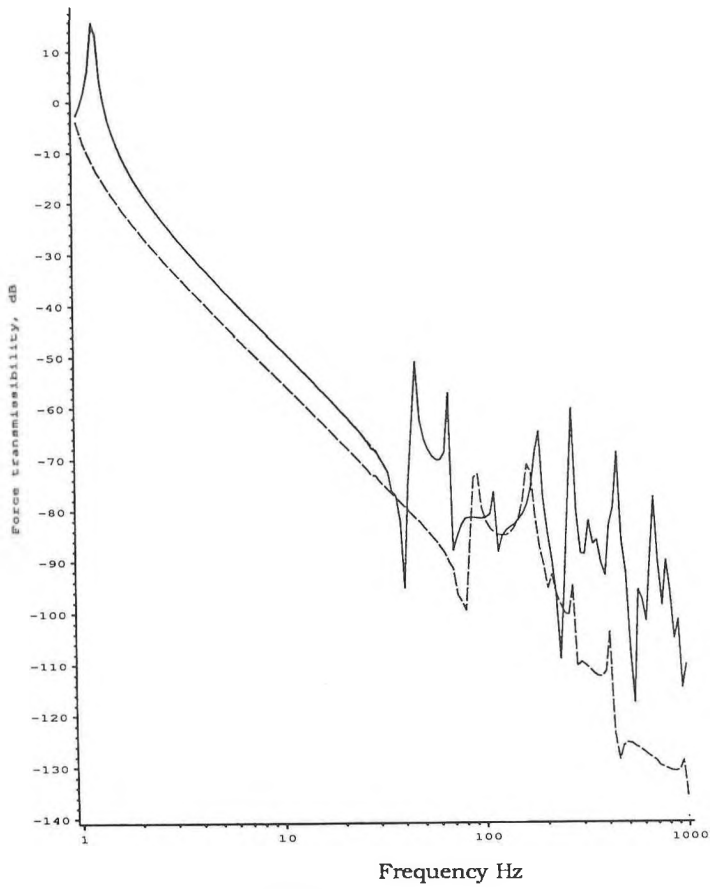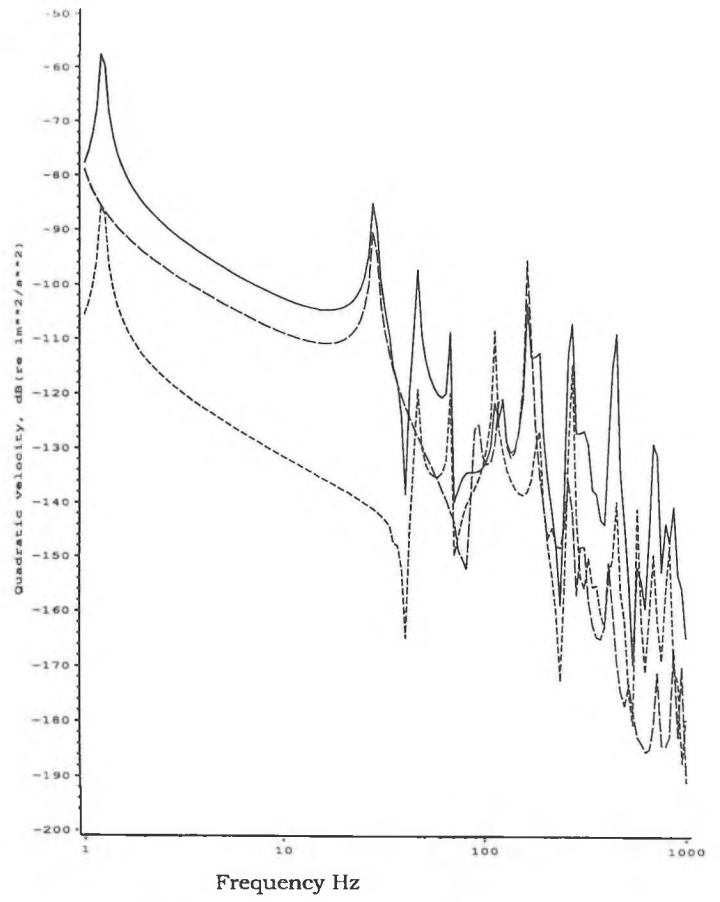
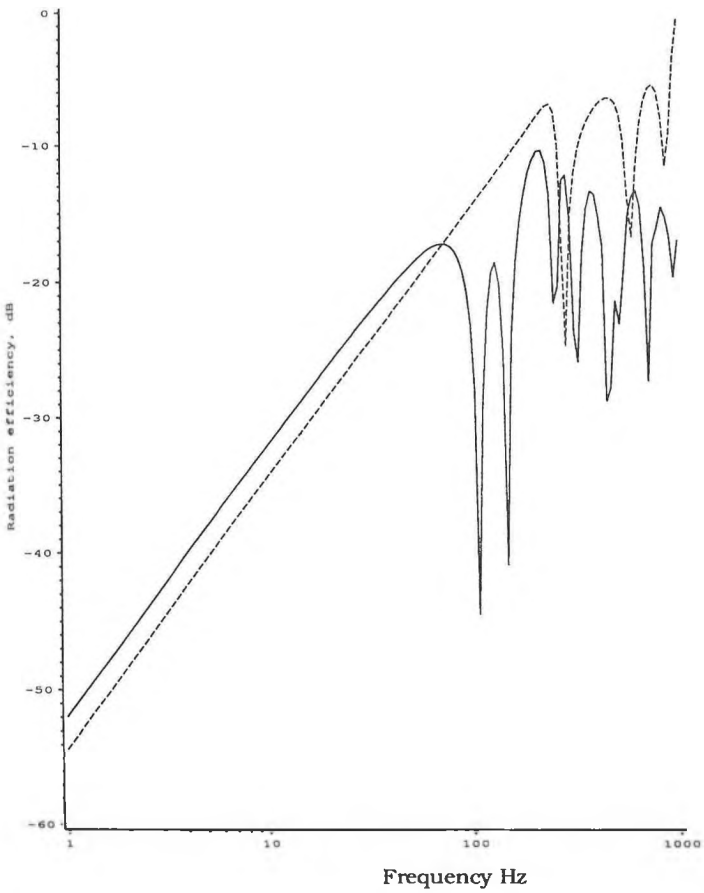Fig. 1 a : Force transmissibility

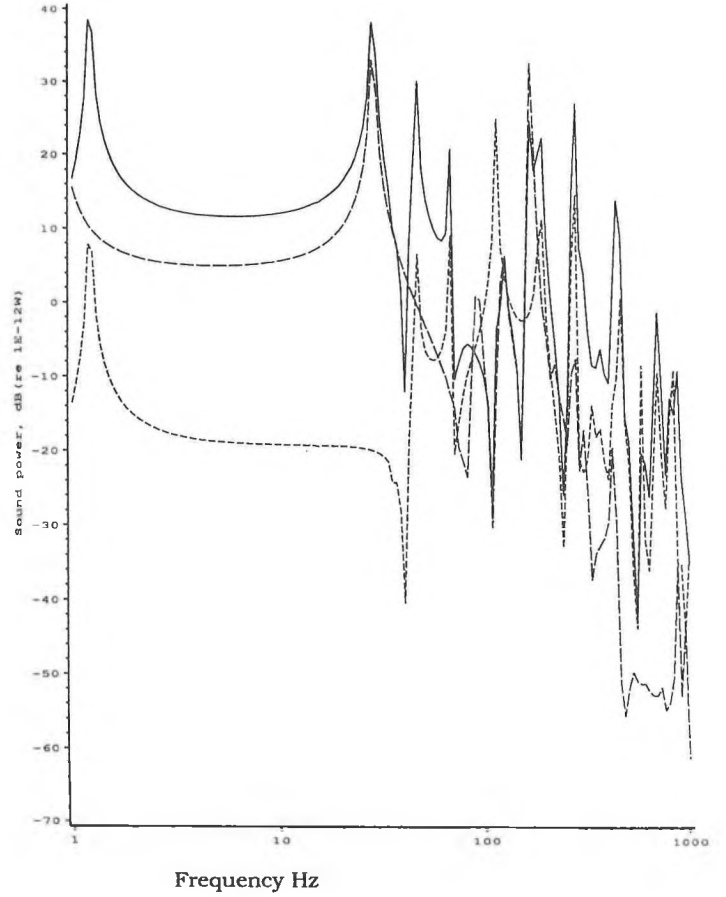Fig. 1 b : Quadratic velocity

Fig. 1 c : Radiation efficiency

Fig. 1 d : Sound power

Fig. 1 : Numerical results for various stiffeners installation
_____ no stiffener; - - - - -   four stiffeners, top plate; .... four stiffeners, bottom plate