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CALCULATION OF THE ACOUSTIC RADIATION OF A PARALLELEPIPEDIC STRUCTURE BY USING ACCELERATION MEASUREMENTS

PART 1: Evaluation of inaccuracies attached to the simplifications of the model in the case of a single vibrating side

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The determination of the acoustic pressure by a vibrating structure from velocities needs a great amount of measurements and calculations and the direct use of complete formulation is not possible in industrial situations.

The present paper proposes to calculate the radiated acoustic pressure by using velocity measurements and a simple software based on the monopoles distribution concept. The theoretical basis of the calculation is only available for a vibrating plate located in a rigid baffle. Nevertheless, this simple formulation is used in the case of a rectangular box with a single vibrating side with and without baffle.

The good agreement between experimental and theoretical results in this case allows us to use such a methodology for 3D structures with a pressure signal as reference signal.

1. Introduction

The predictive methods of noise radiated by vibrating structures are of a great interest in numerous situations, but the available tools are often too complicated, especially for small manufacturers, who need simplified methods. Far field sound prediction, performed from the velocities of the structure, is an important step of the calculations. This prediction is usable either with calculated velocities for a machinery at the design stage, either from measured velocities obtained on an existing machinery for a diagnostic. This method is very helpful in industrial cases, to extract the noise due solely to the structural vibrations from aerodynamic noise, or to evaluate the contribution of each part of the structure to the radiated noise.

A very simple method, based on a simple layer potential (monopole sources) with the Green's function corresponding to a half infinite space is used. In the academic case of a baffled plate in an anechoic chamber, where all the assumptions are verified and where all useful parameters can be measured, the predicted radiated noise is generally in good agreement with the measured noise. When such a formulation is used in a more industrial case performed for example by a vibrating rectangular box, various sources of inaccuracies are present. The lake of baffle, the spatial sampling, the choice of the reference signal are considered in the first part of this paper. In the second part, it is shown that in spite of simplifying assumptions, this method can already be helpful to evaluate the contribution of each plate of a vibrating rectangular box to the radiated noise.

2. Calculation model

In the case of a vibrating structure (surface S) placed above a reflecting rigid baffle Σ_0, the governing equations are

$$\Delta P(M) - k^2 P(M) = 0$$

$$\frac{\partial P(M_0)}{\partial n} = \begin{cases} -j\rho_0 \omega V(M_0) & \text{if } M_0 \in S \\ 0 & \text{if } M_0 \in \sum_0 \end{cases} \tag{2.1}$$

with $P(M)$ radiated pressure (Pa), k wave number (m^{-1}), ρ_0 air density (kg/m^3), ω pulsation (rad/s), $V(M)$ velocity (m/s).
The prediction of the radiated pressure uses Green's theorem

$$P(M) = \iint_s \left((P(M_0) \cdot \frac{\partial G}{\partial n(M_0)}(M,M_0) - \frac{\partial P}{\partial n(M_0)} \cdot G(M,M_0) \right) dS, \tag{2.2}$$

where $G(M,M_0)$ is the Green's function that takes into account the boundary conditions of the problem (i.e. the reflecting surface). In the academic case, where the vibrating structure is a baffled plate, the first term of the relation (2) (dipole sources) is equal to zero and the the radiated pressure can be expressed as:

$$P(M) = -\iint_s \frac{\partial P(M_0)}{\partial n_{(M_0)}} G(M,M_0)\, dS, \tag{2.3}$$

From a practical point of view, the radiated acoustic pressure is calculated from vibrating velocities measured in several points on the plate using:

$$P(M) = \mathrm{i}\rho.\mathrm{c}.\mathrm{k} \sum_{i=1}^{N} V(M_i)\, G(M,M_i) \Delta S_i \tag{2.4}$$

As previously specified, this formulation is only valid in the case of a baffled plate radiating in a half domain. It is however used for the determination of the acoustic radiation of the upper plate of a rectangular box, with and without baffle. Comparisons between measured and calculated pressure in the two cases are performed in the aim to evaluate the corresponding inaccuracies.

3. Experimental setup

The experimental setup included mainly a rectangular box (600 × 400 × 300 mm) whose all faces are rigid (thickness 20 mm) except the upper plate (thickness 5 mm). Each edge of this plate is fixed to the rigid frame of the box. The upper plate is excited by an electrodynamic actuator fixed inside the box and supplied by a random signal.

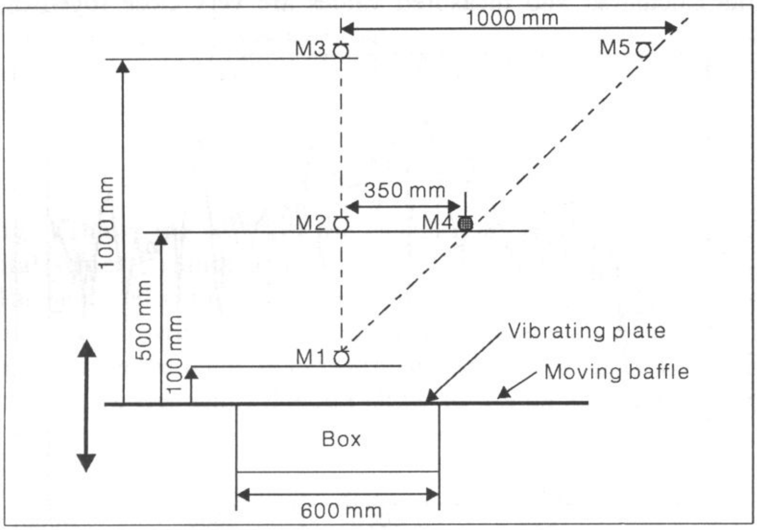

Fig. 1. Experimental setup.

The box is included in a test bench (Fig. 1) situated in a quiet room. The different parts of this test bench are:

— a plane rigid baffle which can move vertically,

— a set of five microphones BK 1/2″ located at different points (M_1 to M_5) specified on the Fig. 1 for acoustic pressure measurements,

— a laser vibrometer POLYTEC OFV 3000 including an optical probe whose displacements are automatically provided by a robot,

— a computer (MASSCOMP MC 5500) to drive the robot during the spatial scanning of the vibrating plate and to perform the acquisition and the signal processing.

4. Results

4.1. *Academic case*

The first tests are performed to obtain as good results as possible. In this aim, the spatial sampling of the plate needs small cells depending on the frequency range of interest (0 – 4000 Hz). The sound pressure levels are calculated from 117 velocities (9 × 13 points) measured on the vibrating plate. With this spatial sampling, the distance between two following measurement points is smaller than the half of the bending wavelength. The calculations need a phase reference signal that is given by a force transducer located between the plate and the electrodynamic actuator. This signal contains all the frequency components and is for this reason the best possible reference. The Figs. 2 and 3 show the comparison between measured and calculated pressure in two locations: in the near field (point 1) and in the far field (point 5). In the near field, the calculated and measured values are very close together in all the

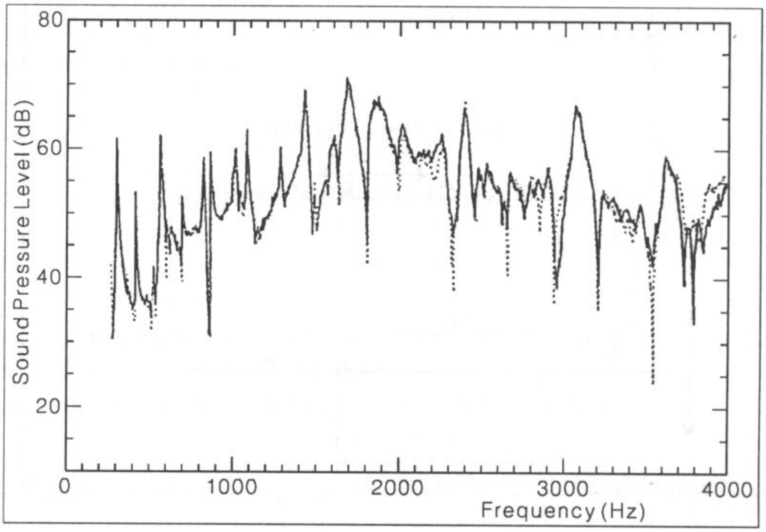

Fig. 2. Plate with baffle measured and calculated sound pressure level at point no 1 (≈ near field) ..... calculation ——— measurement.

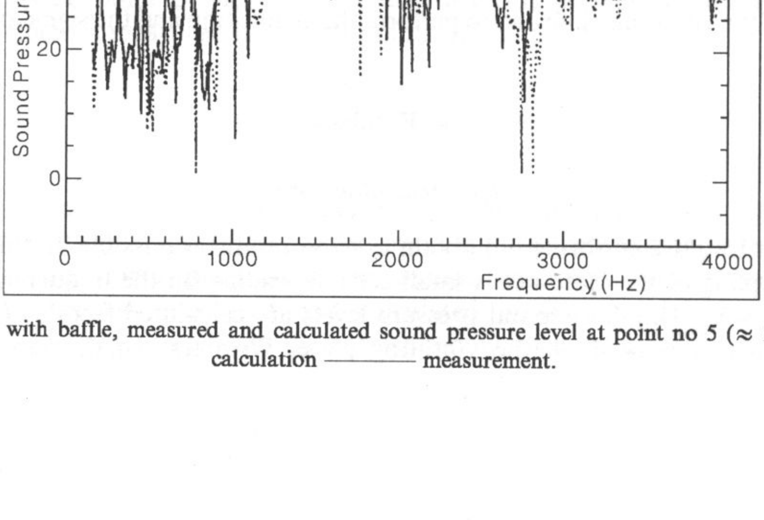

Fig. 3. Plate with baffle, measured and calculated sound pressure level at point no 5 (≈ far field) ..... calculation ——— measurement.

frequency range (above and under the critical frequency: 2400 Hz). In the far field, the agreement is very good up to 2000 Hz and the inaccuracies are weak between 2000 Hz and 4000 Hz.

In industrial conditions, such a methodology can't be used because:

— the LASER velocimetry with automatic spatial sampling device is rarely usable,

— the signal issued from a force transducer is not available and can't be used as phase reference,

— the vibrating plates are not baffled.

Consequently, the induced inaccuracies have to be evaluated, preferably in laboratory conditions.

4.2. *Influence of the spatial sampling*

The Fig. 4 shows the effect of the calculations size of the cells (i.e.number of experimental velocity values used for the calculation). As planed by the theory, calculated at measured acoustic pressures are in good agreement in the frequency range where the distance between measurement points is smaller than the half wavelength of the bending waves in the plate. In industrial conditions, it will be necessary to use this methodology in low frequency domain either to use an automatic scanning device.

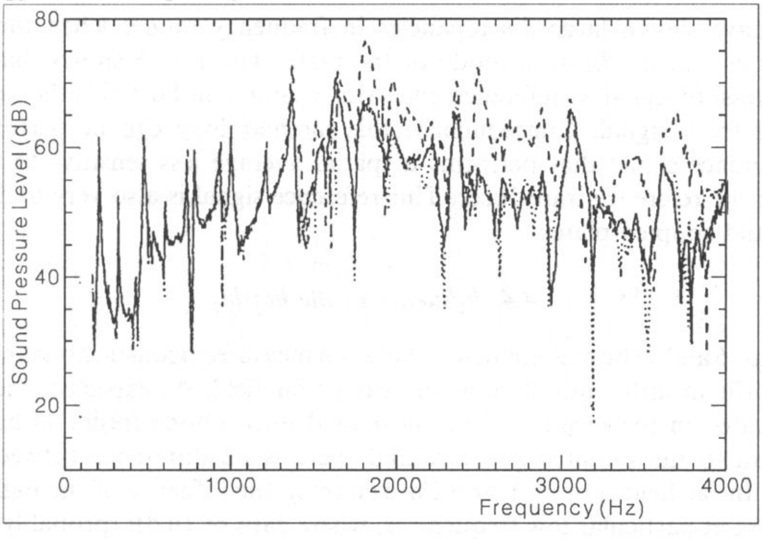

Fig. 4. Influence of the spatial sampling at point no 1. — — — — calc. with 24 points, ... calc. with 117 points, ———— measurement.

4.3. *Influence of the reference signal*

As shown previously, calculated and measured acoustic pressures are in good agreement with a force signal as phase reference. Unfortunately, this signal is rarely available in industrial cases and numerous tests using an acceleration signal as

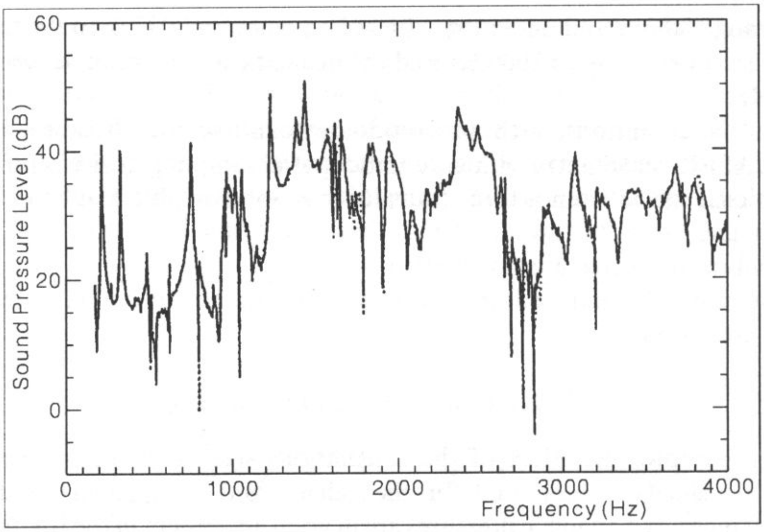

Fig. 5. Comparison between calculated acoustic pressures with force or pressure as signal reference (at point 5) .... calc. ref. = micro ——— calc. ref. = force.

reference have shown large discrepancies in frequency ranges when the reference transducer is near a vibration mode of the plate. The Fig. 5 shows that using an acoustic pressure signal as reference gives (for example in far field) the same results than using force signal. Consequently, this methodology can be performed with a such reference signal that performs a spatial average less sensitive to the spatial location of the reference transducer. This reference signal is also very useful for two vibrating and coupled plates.

4.4. Influence of the baffle

The Figs. 6 and 7 show comparisons between measured acoustic pressures with and without baffle in different locations in near or far field. As expected, the vibrating surface located in the vicinity of the near field microphone (point 1) has a major contribution to the radiated pressure and there is no difference between the two situations. In far field (points 1 or 5 for example), the infuence of the baffle is often weak, except at particular low frequencies, where gaps of 10 dB (probably due to the diffraction by the box) can arise. Generally these differences don't modify the global sound level. Nevertheless, they can be of great importance with harmonic excitation in low frequency domain. The Fig. 8 shows in far field the comparison between calculated pressure and measured pressure without baffle. From a theoretical point of view, the first term of the relationship (2), is different from zero and the radiated pressure included the contribution of dipoles sources (double layer potential). As previously shown, this term is neglected in the present calculation of the radiated pressure and the inaccuracies induced by this simplification are small in the studied case.

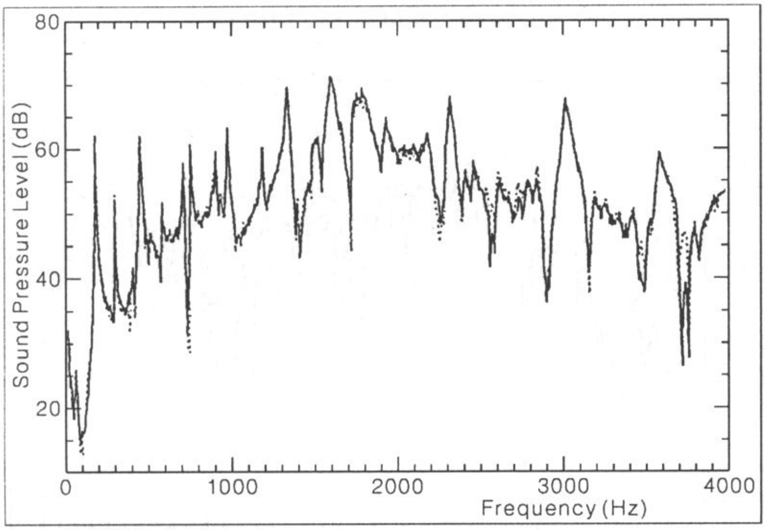

Fig. 6. Comparison between measured acoustic pressure with and without baffle (at point 1) ..... with baffle ——— without baffle.

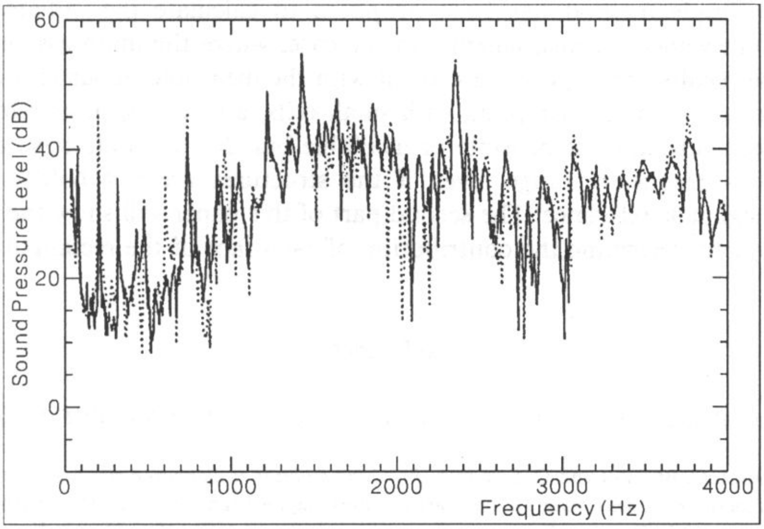

Fig. 7. Comparison between measured acoustic pressure with and without baffle (at point 5) ..... with baffle ——— without baffle.

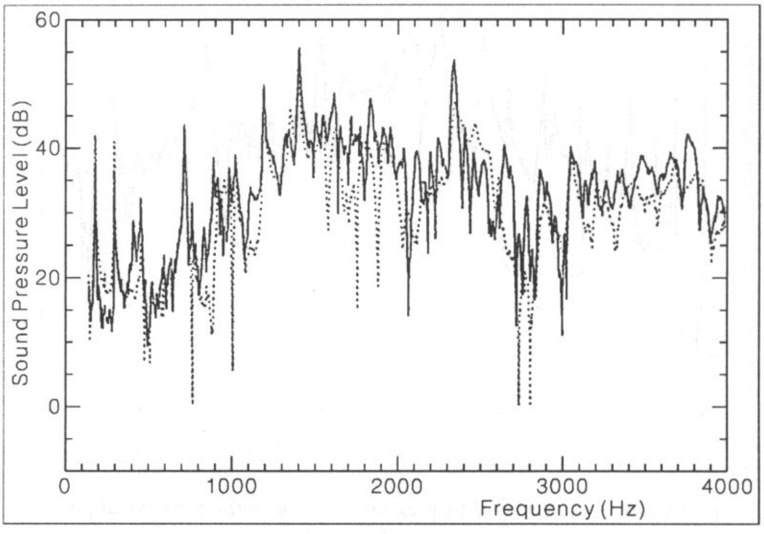

Fig. 8. Comparison between measured acoustic pressure without baffle and calculated pressures ..... calculation, ——— measurement.

5. Conclusions

A very simple method has been proposed to calculate the radiated acoustic pressure from velocity measurements. In the case, where the main assumptions are verified, the results are in good agreement with the measured acoustic pressures. In industrial cases, a spatial sampling with small cells, a force signal as reference and a baffled structure are not possible or available but this methodology can be very useful in low frequency range, even if the structures are not baffled and with a pressure signal as reference. The second part of this paper will show the use of this methodology to determine the contribution of each face of the rectangular box.

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