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A PHYSICALLY BASED STRATEGY FOR ROBUST FEEDBACK CONTROL OF NOISE RADIATION FROM A BAFFLED PLATE

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ABSTRACT
The active control of the noise radiation from a baffled plate is considered with a simple SISO control strategy involving a volume displacement sensor and a set of point force actuators driven in parallel by a single power amplifier. The actuators location is chosen to obtain an open-loop transfer function which presents the properties of a system with collocated actuator and sensor; the search procedure uses a genetic algorithm. The ability of a simple *lead* compensator to control this SISO system is numerically demonstrated with a glass plate.

1 - INTRODUCTION
This study is based on a fact which is not always accepted by the control community: that the performance and robustness of a control system often relies far more on the design of the open-loop system (i.e. the choice and location of sensors and actuators) than on the specific compensator design methodology used. Accordingly, a careful vibroacoustic analysis of the baffled plate is conducted to reduce the open-loop system to a SISO control problem with a number of desirable features from the point of view of controllability and robustness. The strategy proceeds in two steps:

- An array of piezoelectric patches located at a regular mesh is connected to a linear combiner to produce a single-output volume displacement sensor; the coefficients of the linear combiner are determined from experiments to minimize the error between the measured and reconstructed frequency responses. The volume displacement is known to be closely related to the sound power radiated by a baffled plate at low frequency [1]; this brings some limitation to the bandwidth of the control system. The volume displacement sensor used in this study is described in [2,3].
- A small set of actuators (either point force or piezoceramics, although this paper will consider the point force only) is constrained to operate with the same voltage to achieve a single input system; the location of the actuators is then optimized to provide the open-loop frequency response function (FRF) with the desirable features:
  - Alternating poles and zeros are sought within the control bandwidth to enhance the immunity with respect to the parametric uncertainty [4].
  - The magnitude of the resonance peaks is maximized within the control bandwidth to increase the control authority.
  - The magnitude of the resonance peaks is minimized near and right after the cross-over frequency to improve the gain margin and reduce spillover.

The actuator placement uses a genetic optimization algorithm. The key in developing efficient genetic algorithms is to select a fitness function which, at the same time matches the physical objectives and is easy to calculate. This is discussed in the next section.

Having designed a *nice* open-loop system, the final step consists of designing the feedback compensator. This paper illustrates that a low order, model independent, classical compensator produces a substantial low frequency attenuation.

2 - OPTIMIZATION OF THE ACTUATORS LOCATION

The optimization of the actuators location to achieve the features of the FRF described above is the main innovation of this paper. Our implementation of the genetic algorithm uses the MATLAB toolbox GAOT [5]. The challenge in this optimization problem is to formulate a fitness (cost) function which is easy to calculate and, at the same time, reflects the physical requirements of the open-loop FRF. This is discussed below:

The alternating poles/zeros requirement can be expressed by using an interesting property of undamped SISO structural systems: if two neighbouring modes are such that their residues have the same sign in the modal expansion of the open-loop FRF, there is always an imaginary zero between them [6]. We thus define the following fitness function to be maximized:

$$F_1 = \sum_i sign\left[\phi_i(a)\, V_i\right] \tag{1}$$

where $sign(.) = 1, 0, -1$ according to the sign of the argument, V_i is the volume displacement for mode i and $\phi_i(a)$ represents the sum of the modal amplitudes at the actuators, (remember that the actuators behave as a single actuator). The sum over i extends to all the modes belonging to the frequency band where alternating poles and zeros want to be enforced. Clearly, maximizing F_1 is equivalent to enforcing positive residues in the modal expansion of the FRF.

Next, the good controllability of the modes within the bandwidth calls for a large modal amplitude at the actuator for all the modes within the controller bandwidth. This can be enforced by defining the second contribution to the fitness function:

$$F_2 = \sum_i \alpha_i \left|\phi_i(a)\right| \tag{2}$$

where α_i are weighing factors. Finally, in order to minimize the controllability in the cross-over region and slightly beyond, the following contribution can be added:

$$F_3 = -\sum_j \beta_j \left|\phi_j(a)\right| \tag{3}$$

this term is negative because the fitness function is maximized; β_j are also weighting factors. The global fitness function is

$$F = F_1 + F_2 + F_3 \tag{4}$$

Notice that the above fitness function is straightforward to compute from the knowledge of the mode shapes only; this property is essential to speed up the optimization process. Note also that the limit between the modes contributing to the various contributions of the fitness function is flexible; some of the modes near crossover may be included in F_1 to guarantee alternating poles and zeros (in order to achieve phase stabilization), but also in F_3, to minimize their impact on the open-loop FRF.

3 - APPLICATION

The proposed strategy has been applied to the control of a glass plate of 1.28m ×.58m ×4mm thickness. The numerical study is performed with an analytical model of the plate, and we assume a perfect knowledge of the volume displacement output. Figure 1 shows the open-loop FRF for a single actuator arbitrarily located.

The frequency limit of the modes included in F_1 is chosen close to 250 Hz to include the first three modes contributing to the volume velocity [mode (1,1) at 36 Hz, (1,3) at 85 Hz and (1,5) at 182 Hz]. The foregoing procedure has been applied for 1, 2 and 4 actuators working in parallel; in every case, an alternating pole/zero configuration is easily obtained, but a larger number of actuators tends to improve the behaviour in the roll-off region, which eventually will allow larger gains. Figure 2 shows the open-loop FRF for 4 actuators; the actuators configuration is shown on the figure.

4 - FEEDBACK CONTROL

To illustrate the benefit of the optimized open-loop FRF in the controller design, a lead compensator

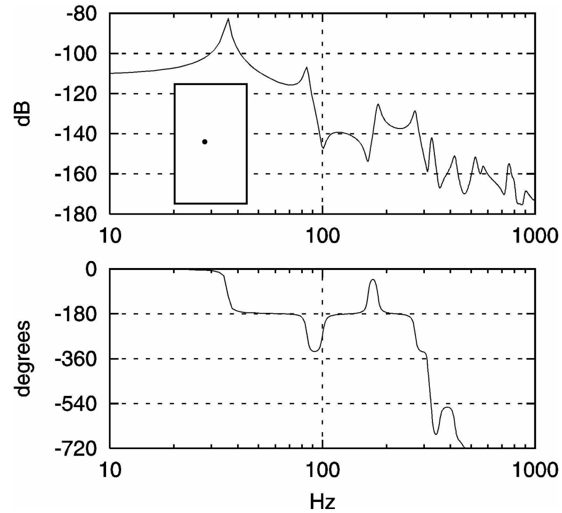

Figure 1: Open-loop FRF with arbitrary actuator configuration.

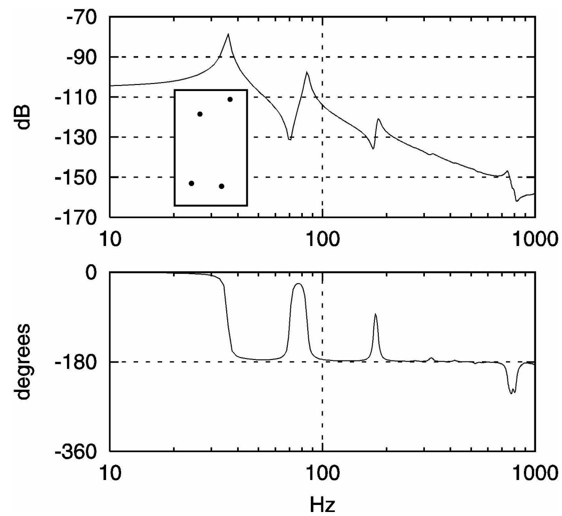

Figure 2: Open-loop FRF with 4 actuators optimally placed.

$$H(s) = g\frac{Ts+1}{\alpha Ts+1} \tag{5}$$

has been used. The three parameters appearing in the control law can be adjusted on phase and gain margin considerations. The performance of the control system is evaluated with respect to a plane wave acoustical perturbation. Figures 3 and 4 show the power spectral density (PSD) of the volume displacement and the radiated sound power (calculated by discretizing the plate into elementary piston-like radiators) over a bandwidth of 350 Hz. The comparison of Figs. 3 and 4 shows that, as expected, the sound power radiation attenuation is limited to the modes participating to the volume displacement; the other modes (which are unobservable from the volume displacement) still radiate and can be excited by the control (spillover) and the external disturbance. Table 1 illustrates the global attenuation of the volume displacement and the sound power radiation (in dB) in various frequency bands for optimal actuator configurations involving 1, 2 an 4 actuators.

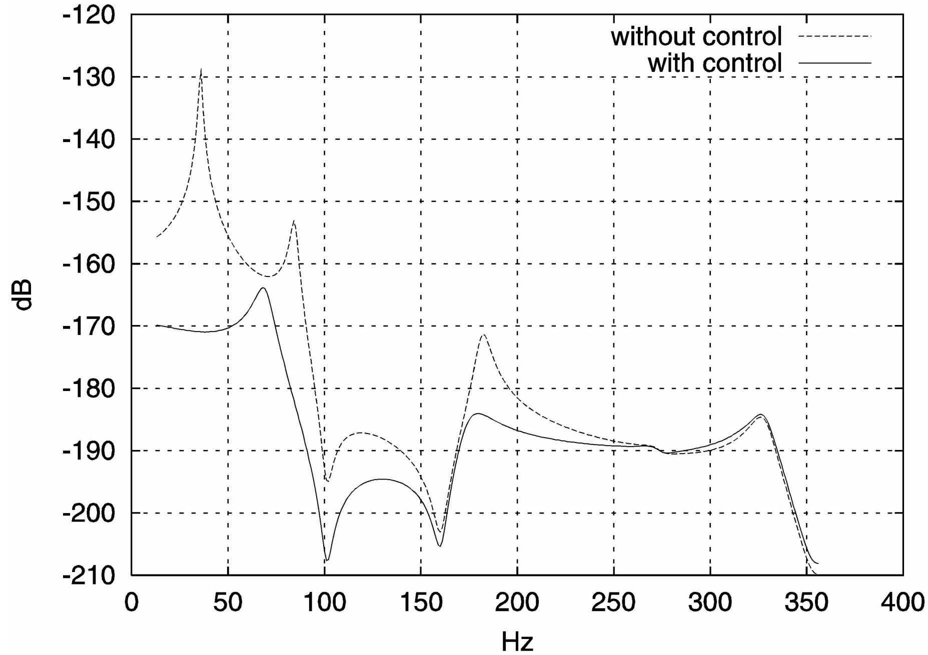

Figure 3: Volume displacement PSD (4 actuators optimally placed).

Bandwidth	13-56 Hz		13-224 Hz		13-355 Hz	
Actuator number.	Vol	Pwr	Vol	Pwr	Vol	Pwr
1	14.5	17	12	4.5	11.5	3.5
2	18	21	14	7.5	13.5	5.2
4	26	30	19	9	18.5	6

Table 1: Volume displacement and sound power radiation (dB) reduction for various optimum actuator configurations and various frequency bands.

5 - CONCLUSION

A strategy for feedback control of noise radiation of a baffled plate has been presented. The innovative feature consists of optimizing the actuators location to achieve an open-loop FRF with desirable properties. It has been demonstrated numerically that such a system can be controlled easily without the availability of a state space model.

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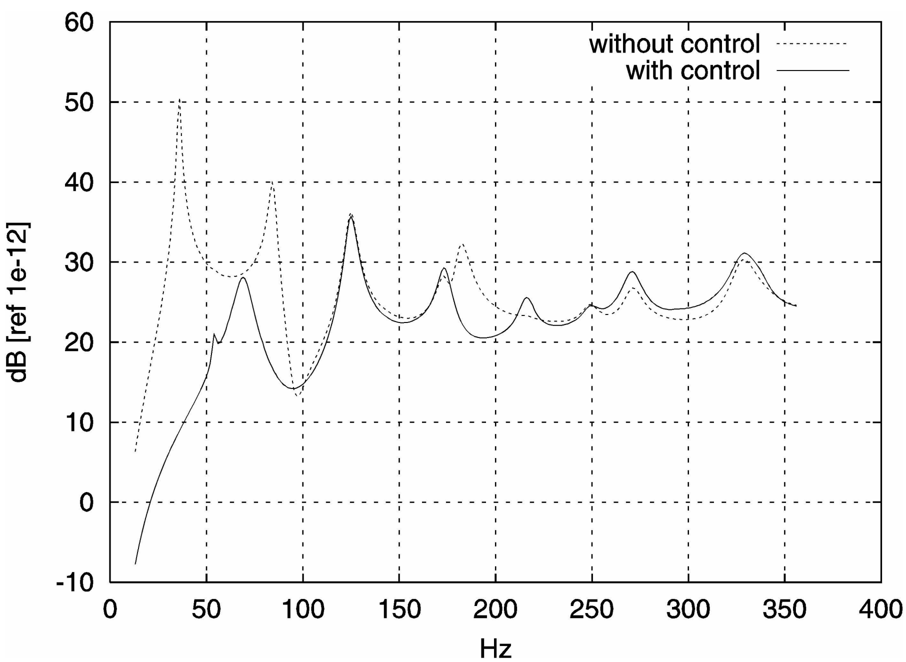

Figure 4: Sound power radiated PSD (4 actuators optimally placed).