No noise control with a smart board: a comparison between active and semi-passive approaches

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The present paper deals with a comparison of two noise control techniques developed separately; active and semi-passive approaches. A closed rigid box with a loudspeaker inside is designed so that sound pressure is transmitted through a smart board which consists in a clamped steel plate with piezo patches. The present active control technique uses the patches as actuators and a microphone as feedback. The semi-passive technique is a brand new control technique which uses a non-linear approach in which the voltage of piezoelectric patches is switched through an inductance for a very brief period of time when it reaches its maximum or minimum. They are compared and discussed in terms of efficiency on sweeping time response and robustness in non-linear regime. The results revealed that both techniques have different advantages and disadvantages.

Keywords: Self-sensing actuator, Semi-passive technique, Synchronized Switch Damping on Inductor (SSDI), Noise control, Frequency shift

I. INTRODUCTION

The studies with built-in sensors and actuators have been widely carried out aiming to realize various functions of smart structures, such as vibration control, noise control, health monitoring and so on. In the matter of intelligent material researches, reduction of noise and vibration becomes a top priority research topic for various industrial activities. With such a potential application variety, various damping methods had been designed using piezoelectric materials. The authors have studied two different approaches, both of which have peculiar points of interest. They are compared and discussed in terms of efficiency on sweeping time response and robustness in non-linear regime.
II. THEORIES

II-A. Active approach

The active control technique is based on a controller (FIR filter) whose parameters are automatically adjusted via a LMS algorithm in order to minimize the feedback signal, in this case the sound pressure measured on the microphone.

The advantage of this technique, compared to more complex strategies such as Self-Sensing Actuation (SSA),\(^1\) lies in its relative simplicity, and it is possible to control vibration almost independently on the piezoelectric patches position. This is especially important in that case where the position of the patches are optimized for the semi-passive technique.

![Diagram of experimental setup](image)

Fig. 1. Experimental setup for active control.

The FIR filter is expressed by a vector of coefficients, \(\mathbf{h}\). When a time series \(\mathbf{X}\) is applied to the filter, its output is a function of the last \(m+1\) values of signal \(\mathbf{X}\), where \(m+1\) is the number of filter coefficients. \(D_m\) is an operator to create vectors of time series of length \(M\), \(Z^{-1}\) is an operator which delays the signal by one time step, and \(y(n)\) is the control input. The vector \(\mathbf{X}\) and control input \(y(n)\) can be expressed in the following form:

\[
\hat{\mathbf{X}} = D_{M+1} \{ e(n-1) \} \quad (1)
\]

\[
y(n) = \mathbf{h}^* D_{M+1} \{ e(n-1) \}. \quad (2)
\]

The coefficients of the FIR filter are updated using the Filtered-X LMS algorithm so that the error signal becomes minimal. The updating equation can be expressed in the following form:

\[
\mathbf{h}(n+1) = \mathbf{h}(n) - 2\mu e(n)D_{M+1} \hat{\mathbf{X}}^* D_{M+2} \{ e(n-1) \} \quad (3)
\]

II-B. Semi-passive approach

Whole of the present study is a quite original work. It is a very simple non-linear approach requiring only switches which are triggered on the structure motion. Without getting into details, the very basics of the approach can be described as follows. If we consider a linear oscillator with piezo element generating a voltage \(F(t)\), proportional to the displacement \(u\), then, the general equation writes,

\[
M\ddot{u} + Ku = F(t) + aV(t). \quad (4)
\]

The main question is now: How to shape \(V\) versus \(u\) to create a strong damping effect? It appears that switching the voltage of piezoelectric patches on a resistive or on an inductive shunt seems to be the best solution. Inductive switching was selected since it exhibits larger damping as shown in Fig. 2.

![Graph showing displacement and voltage](image)

Fig. 2. The voltage on the piezoelectric elements (thick line) and the displacement in SSDI configuration.

The control circuit requires very little energy and can be made completely self-powered if associated with an energy harvesting device using the same piezo elements. This technique is known as the Synchronized Switch Damping on Inductor (SSDI) technique (see more details in Ref. 2).

III. MATERIAL AND EXPERIMENTAL SETUP

III-A. Smart board definition

The configuration of a steel plate, used as the smart board, is 300*300 mm. The plate was clamped on 20 mm so that the vibratory area is 260*260 mm. Four piezo elements of 36*18*0.3 mm were bonded on the surface, close to the edge, at the center of edge line, in order to enhance the electromechanical
coupling of the structure.

The Finite Element Analysis (FEM) simulation was performed to determine the different resonance modes of the plate. The computed resonant frequency in open (OC) and short circuit (SC) configuration and electromechanical factors $k$ are listed in Table 1 for the first ten modes.

Table 1. FEM results of the first 10 modes, resonance frequencies and electromechanical factors.

<table>
<thead>
<tr>
<th>Mode</th>
<th>OC freq</th>
<th>SC freq</th>
<th>$k$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>144.9407</td>
<td>144.2045</td>
<td>10.06</td>
</tr>
<tr>
<td>21</td>
<td>292.7621</td>
<td>291.8116</td>
<td>8.05</td>
</tr>
<tr>
<td>12</td>
<td>292.7662</td>
<td>291.8148</td>
<td>8.05</td>
</tr>
<tr>
<td>22</td>
<td>423.7601</td>
<td>423.7597</td>
<td>0.14</td>
</tr>
<tr>
<td>22b</td>
<td>521.4902</td>
<td>520.7038</td>
<td>5.49</td>
</tr>
<tr>
<td>22t</td>
<td>531.4591</td>
<td>529.0400</td>
<td>9.53</td>
</tr>
<tr>
<td>32</td>
<td>649.8718</td>
<td>649.5262</td>
<td>3.26</td>
</tr>
<tr>
<td>23</td>
<td>649.8766</td>
<td>649.5300</td>
<td>3.26</td>
</tr>
<tr>
<td>41</td>
<td>840.4615</td>
<td>838.5758</td>
<td>6.69</td>
</tr>
<tr>
<td>14</td>
<td>840.4671</td>
<td>838.5814</td>
<td>6.69</td>
</tr>
</tbody>
</table>

In most of the resonance modes, very good coupling factors are obtained except for the first 2-2 resonance mode.

When subjected to a white noise excitation, the significant sound pressure is mainly generated due to the first and the fifth modes resonance, since the other modes present a low acoustic flow and since the wave length is much larger than the vibrating area. Due to high electromechanical coupling, it should be possible to control until the tenth resonance mode except 2-2 mode. For the sake of clearness, however, the study was focused only on the first mode.

III-B. Experimental setup

The smart board was clamped to the closed box containing loudspeaker at the bottom. The other walls of the box are rigid and the noise produced by the speaker inside the box can be transmitted to the outside only via vibration of the plate. It was located in the anechoic chamber. A microphone is set in front of the plate in order to measure the sound level.

IV. RESULTS AND DISCUSSIONS

IV-A. Sweeping time effect

Fig. 3 shows the results of sweeping speed damping effect. The results show that compared to active control, the semi-passive performance decreases while increasing the sweeping speed.

![Fig. 3. Sweeping speed effect to damping effect.](image)

With high sweeping speeds, the resonance is excited only for a very short time (comparable to the wavelength). Hence we face more a pulse response than a steady state response. Voltage increase induced by switching process is thus limited to the actual number of periods, until the signal becomes lower than detection sensibility (exponential decrease due to the mechanical losses of the plate). Consequently the damping decreases with the sweeping speed. On the contrary the voltage is applied almost instantly in case of active control, and the damping remains robust as shown in Fig. 3.

In the same manner, the actual semi-passive process does not work on broad bandwidth signals in which the resonance is excited only for very short times, such as random noise. The strategy has to be refined to be efficient in such a case. This work is on going now.

IV-B. Effect of frequency change due to non-linearity

By increasing the excitation level, mainly two phenomena appear: (1) Resonance frequency shift and (2) Non-linear behavior, as shown in Fig. 4. Fig. 5 shows the damping effect versus excitation levels.

Both techniques remain robust until a "breakpoint" around 20V which corresponds to the appearance of
a heavy nonlinear behavior. Both control techniques tend to "linearize" the resonator behavior. In the nonlinear regime, the mechanical energy is "spent" in generation of higher harmonics and compensation of increased losses. Hence we expect a saturation of the displacement vs. mechanical energy. Both controls remain effective until the natural saturation occurs when the non-linearities becomes important.

![Diagram of vibration amplitude for different excitation amplitudes without control.](image)

**Fig. 4.** Vibration amplitude for different excitation amplitudes without control.

![Diagram of excitation level change to damping effect.](image)

**Fig. 5.** Excitation level change to damping effect.

**IV-C. Frequency change effect**

In the previous case, it was hard to separate the effect of nonlinear behaviors and the effect of frequency shift. In order to identify only frequency shift effect, a mass, small magnet, was bonded at the center of the plate and a small excitation level was induced. The resonance of the plate was excited with frequency sweep of 0.3 Hz/sec and the excitation level of 0.1V. Frequency shift up to 11% was examined.

The results are given in Fig. 6. It is clearly shown that the performance of active control decreases to one third of its maximum value in 5% frequency shift. The performance of the semi-passive technique remains, on the contrary, constant for all frequency shifts up to 11%.

![Graph of normalized damping for different frequency shifts.](image)

**Fig. 6.** Normalized damping for different frequency shifts (damping with 0% shift, 8dB active, and 7.4dB, semi-passive).

Active control strategy requires a complete system identification in order to set the FIR parameters. A modification of the system behavior causes a degradation of control performance because the FIR parameters are not adapted to the new system parameters. On the opposite, semi-passive strategy does not need any identification so it is robust enough to stand frequency shift up to 11% without performance degrading.

**V. CONCLUSION**

The comparison shows that both techniques lead to comparable results (6 to 8 dB in the considered case). The active approach is much better for broadband signals while semi-passive is more robust for frequency shift. The semi-passive technique can be self-powered, wireless and does not required any computing facilities.

**REFERENCES**


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