ACTIVE NOISE CONTROL APPLIED TO BUILDINGS COMPONENTS

PACS REFERENCE: 43.50.Ki

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ABSTRACT
Situations and building elements in the construction field, make appealing the application of active noise control to increase the sound reduction index of the windows and to modify the sound absorption of internal walls. Furthermore, the active control would go into operation when needed by the user according to the specific disturbing situation. The work illustrates the evaluation of two innovative real-scale prototypes investigated by the authors: an open window with free-space active noise control and panels fitted to an internal wall with acoustic absorption active control. The results show a sound reduction index improvement up to 16 dB.

INTRODUCTION

Building Acoustics is one field of activity of ITC, the Construction Technologies Institute of the National Research Council, and different methods to improve acoustic insulation are investigated. In order to overcome the limitations of traditional techniques (passive) in insulating low–frequency noise, active noise control was considered and the possibility to control noise passing through an open window was thought to be very attractive. It was decided to apply active noise control to building components, both transparent (e.g. window) and opaque (e.g. partition wall). The main goals were:

- designing two prototypes with short time to market;
- utilisation of devices and elements already commercially available, when possible;
- making the building market segment aware of the ANC potential.

The following configurations were thought to increase the chances of success of active noise control techniques:

a) for the transparent component an acoustical control version and a structural control version;
b) for the opaque component an insulation control and a reverberation adjustment configuration, both with acoustical and structural control version.

The acoustical versions use loudspeakers and microphones as actuators and sensors respectively. The structural versions use piezoelectric elements as actuators. The early tests together with the good

performance of the acoustical solutions convinced us to leave these structural configurations, focusing on the acoustical ones.
The heart of these configurations consists in a commercially available digital board, which allows setting up an active noise control system, based on a FXLMS algorithm. Several control parameters such as number of inputs and outputs, filter taps, factor of convergence and leakage, can be varied. A good performance was achieved in presence of narrow band noise source. Actually we guess that this device could be applied when noise emitted by transformer, conditioning systems, blades, rotors and engines in continuous running must be controlled.

EXPERIMENTAL SET-UP

Several tests were performed both in laboratory and in the experimental building located near the ITC's dwellings. The laboratory consists of two rooms, which are placed side by side, for sound reduction tests on vertical components according to international standards and is designed in order to avoid flanking transmission.
In laboratory the prototypes under test were inserted in an opening of the partition wall, which had a high sound reduction index. The controller (a digital board) and the audio amplifier were placed in the receiving room while a loudspeaker was put in the emitting room to simulate the noise source. A personal computer had the task to generate the source noise while the signal captured by the microphones in the receiving room were sent to a dual channel analyser.

Fig. 1 – Experimental building: southern façade (left); second floor before the insertion of the partition wall (right).

The experimental building is a three-storied building with façades made with large prefabricated concrete panels. The test rooms (its volumes are 56.6 m^3 and 39.2 m^3 respectively), located at the second floor (100 m^2 wide), were divided by inserting a standard equipped wall; the transparent component was placed in the southern façade while the opaque prototype was inserted in the partition wall (see figure 1).

ACTIVE WINDOW

A wooden frame, thick enough to house microphones and loudspeakers, is added to the internal perimeter of a standard-size window (see figure 2). The cables from the loudspeakers and the microphones end into the same terminal board, placed in the lower side of the frame. The amplifier and the digital board in the receiving room are connected to this terminal board. In order to assess the performance varying the number and position both of loudspeakers and of microphones, several houses were prepared.

Fig. 2 – Active window: in laboratory (left) and in the experimental building (right).

Acoustical Control

The window must be considered as a (very short) “duct” within which it is possible to artificially create a “variable impedance plane” able to prevent the penetration of a sound field coming from outside. The aim was to apply a control on the acoustic impedance of the air layer at the interface between the two environments, by suitably positioning sensors and actuators. This configuration controls the disturbing noise passing through an open window.

First a configuration based on one loudspeaker and one error microphone was tested in our laboratory. The sound level reduction was changed from 6 dB to more than 10 dB by varying several control parameters such as filter taps, factor of convergence and leakage. Found a satisfactory configuration, the numbers of loudspeakers and error microphones were changed between one and five and the system was tested using different narrow band sources.

The configuration with three loudspeakers and three microphones proved to get a satisfactory insulation performance while minimising the number of actuators and sensors. The sound pressure level (SPL) waveform recorded by a microphone located in the middle of the open window is showed in figure 3. The active noise control was on during the time period between 15 and 85 seconds. The vertical line indicates the system kick-off. The active control was applied to the closed window too. A sound reduction of about 6 dB was obtained using a narrow band source centred on 130 Hz.

Before inserting the transparent component in the experimental building’s southern façade, the vertical sides of its wooden frame were replaced by two deadening panels in order to get a lighter structure. In order to get a repeatable sound source, a loudspeaker was placed in the yard in front of the window. The narrow band noise, used for testing, was generated by a personal computer and a microphone, connected to a dual channel analyser, was put in the receiving room in order to evaluate the system performance. The controller (a digital board) and the audio amplifier were placed in the receiving room and connected to the terminal board in the lower side of the wooden frame.

Starting from the set of control parameters found during laboratory tests, acoustic insulation was improved by varying the control parameters and, as in laboratory, the configuration with three loudspeakers and three microphones proved to optimise the cost–benefit ratio. Through various adjustments, a sound reduction of about 16 dB was obtained during this testing session using narrow band noise source as shown in figure 3. The active control applied to the closed window has given a sound reduction of about 12 dB (obtained changing several parameters in the control algorithm).

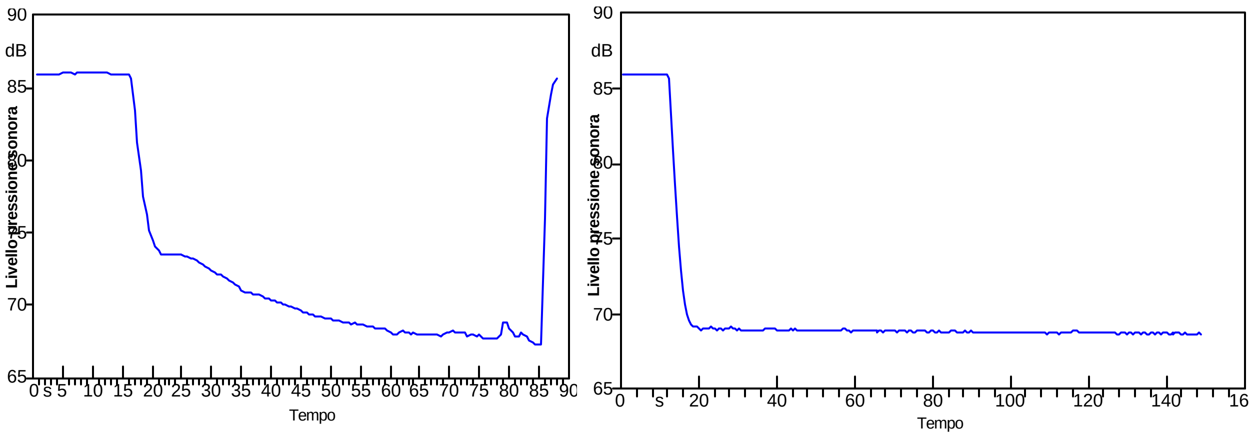


Fig. 3 – SPL reduction obtained with the active window (three loudspeakers and three microphones): left in laboratory; right in the experimental building.

ACTIVE PARTITION

While in most cases transparent components are only concerned by noise coming from outside the buildings, “opaque” components (including any type of wall and modular panels) may be concerned both by outdoor noise (façades) and by noise produced indoors.

It was decided to apply the principles of active control in order to improve the acoustic performance of the panels used as partitions in indoor inhabited premises and offices.

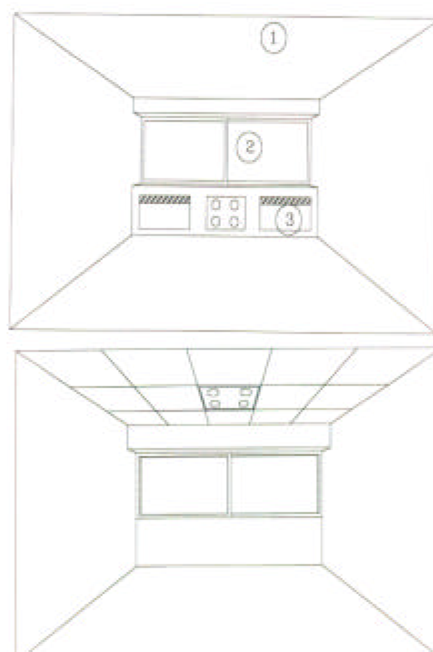
In order to test the opaque configurations with ease, we designed a modular component to be inserted in a standard equipped wall. This modular component can house up to four loudspeakers and microphones in its cavity and allows different panels to be screwed on its sides (see figure 4).

The amplifier and the digital board are positioned within the receiving room and connected to a terminal board placed in the panel under the modular component.

Fig. 4 – Modular component: in laboratory (left) and inserted in a standard equipped wall in the experimental building (right).

Sound Insulation by Acoustical Control

In this configuration a sound field is produced inside a hollow panel through artificial sources (loudspeakers) in order to allow the active control system to minimise the transmitted sound energy. During tests the openings were closed using panels belonging to the standard equipped wall. The narrow band noise was generated by a personal computer and a microphone, connected to a dual channel analyser, was put in the receiving room in order to evaluate the system performance. Acoustic insulation was improved by varying the control parameters (filter taps, factor of convergence and leakage) as necessary. The first tests under laboratory conditions made us move the error microphones from inside the cavity to outside, within the receiving room. The laboratory tests proved that the cost–benefit ratio was optimised using the configuration with only two loudspeakers. In the experimental building the opaque prototype was inserted in the standard equipped wall dividing the second floor into two rooms: emitting and receiving respectively. The controller (a digital board) and the audio amplifier were placed in the receiving room while a loudspeaker was put in the emitting room. A personal computer had to simulate the source by generating the disturbing sound while the signal captured by the microphones in the receiving room were acquired by a dual channel analyser. During the experimental building tests several parameters of the control algorithm were varied in order to improve the acoustic performance of the system, reaching a sound reduction of about 18 dB with narrow band noise.



Reverberation Adjustment

The modal distribution of sound in small environments at low frequencies results in a local amplification of sound and in a meaningful distortion of audio signals. Conventional techniques use a coating with deadening material or the application of either vibrating or resonating panels. Active control allows to realise an alternative solution obtained from the same structure of the previous variant of the active partition through the realisation of an external panel acting as a support for four loudspeakers. The cavity obtained inside the component acts as a sound box for the loudspeakers, as shown in figure 5. Precisely, we intended to control noise emitted inside the receiving room. In laboratory we placed a loudspeaker in the receiving room and fed it with the narrow band noise generated by a personal computer. In the receiving room a microphone, connected to a dual channel analyser, was used to evaluate the system performance. The error microphones facing the loudspeakers were located within the receiving room.

Fig. 5 – Four loudspeakers configuration panel (left) ; hypothesis of insertion in the office environment of the four-loudspeakers active panel (right).

The size of the supporting panel allowed us to utilise a larger loudspeaker's cone than the one of the sound insulation configuration. This helped the device to achieve a better response at low frequencies. The best cost–benefit ratio was confirmed by the configuration with only two loudspeakers. In the experimental building a four-loudspeakers panel was screwed to the modular component inserted in the standard equipped wall. The back side of the modular component was closed with a panel belonging to the partition wall itself. As in laboratory, the same array of sound source and receiving microphones, and the same signal, fed to the reference input of the digital board to simulate a non-acoustical sensor for avoiding feedback, was used to evaluate the system performance. The parameters of the control algorithm were varied in order to improve the acoustic performance of the system reaching a sound reduction of about 27 dB (left side of figure 6).

While testing this configuration, it was decided to apply it to the control of noise passing through the partition wall: therefore a reference microphone was placed in the emitting room. A narrow band noise was generated while a microphone was put in the receiving room; the sound pressure level achieved in a test using a narrow band noise centred about 85 Hz is shown in the right side of Figure 6. The four-loudspeakers configuration achieved an insulation of about 27 dB.

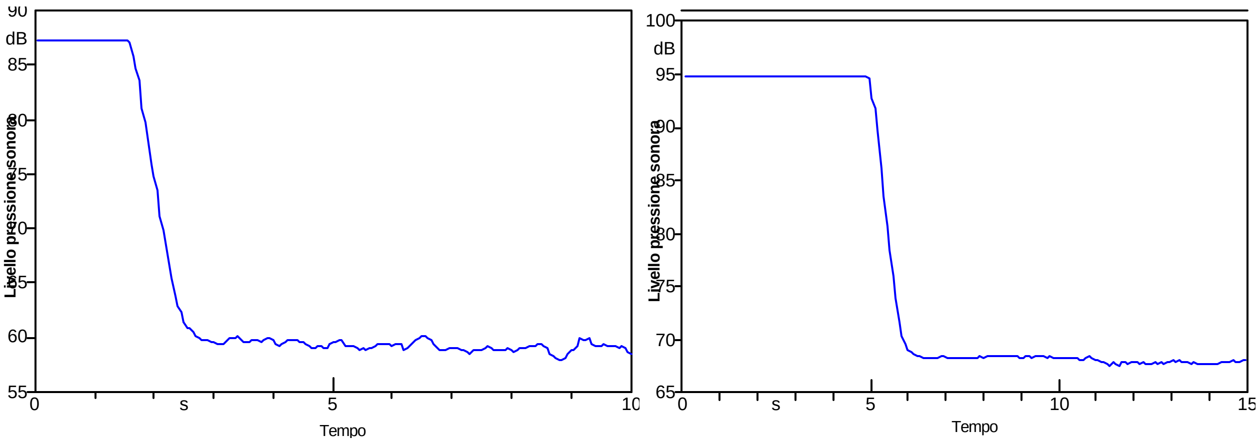


Fig. 6 – Active partition four-loudspeakers configuration; SPL waveform recorded by a microphone located in the receiving room. Left reverberation adjustment, right sound insulation.

CONCLUSIONS

The experimentation has indicated two final configurations as the most promising: the active window and the opaque loudspeakers-panel. The acoustic control version of the transparent component has proven to be very interesting. In effect the good performance of the open window ANC presents this configuration as the only possible solution to a common need: insulation without having to live in a closed box. In the Mediterranean region most people would enjoy keeping the windows open in spring and summer without being annoyed by incoming noise. In fact, in areas near airports, railways, highways and industries a lot of people complain about having to keep all openings closed in order to prevent noise from entering: they feel it as a discomfort.
The four-loudspeakers version of the opaque component has proven to be able to improve both the reverberation adjustment and insulation between rooms. Although the best results were achieved in presence of narrow band noise sources, this doesn't limit excessively the field of application. Actually we guess that this device could be applied when noise emitted by transformer, conditioning systems, blades, rotors and engines in continuous running must be controlled.
The research is still going on under different projects. Several different algorithms for improving the performance are now being investigated. Simulations are performed in order to test several algorithms thought for the control of different kinds of noise source. The two configurations are undergoing a complete re-styling in order to improve their functionality and their ability to be inserted in a building environment. This implies the search for different kinds of loudspeakers and materials in order to make these prototypes more pleasant. At the same time, a new methodology to plan the installation and configure the system is currently being investigated.