ACTIVE NOISE CONTROL IN A TRANSMISSION SURFACE

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ABSTRACT

This work is focussed on active control of an acoustic impedance in a transmission surface. The aim is to avoid noise propagation from the interior of an enclosure through an aperture in its wall using techniques of local noise control. As it is known, acoustic impedance is reduced by the reduction of sound pressure, thus, the objective is to set the impedance value to zero by attenuating the sound pressure using active noise control techniques. With the reduction of impedance, the sound waves of the interior of the enclosure are reflected towards its interior, avoiding the noise transmission to the exterior of an enclosure.

INTRODUCTION

The specific acoustic impedance of a medium, *z*, is described as the quotient between the acoustic pressure and the particle speed.The pressure reflexion coefficient in a boundary, in case of normal incidence is[1]

$$R = \frac{p_r}{p_i} = \frac{1 - z_1/z_2}{1 + z_1/z_2} \qquad (1)$$

where z_1 and z_2 are the characteristic impedances of each medium which separates the boundary. When z_2 tends to zero, the pressure reflexion coefficient tends to -1. Therefore, a positive pressure in the incident wave is reflected as a negative pressure, with the same amplitude, and the pressure transmission is almost zero. In case of oblique incidence, provided the same medium at both sides of the boundary, the reflection coefficient value does not depend on the incidence angle of the sound waves and is equal to (1).

One of the acoustic mechanisms of active noise cancellation in ducts is the reflection[2] of a primary wave by a secondary monopole source. Acoustic pressure at the secondary source position is maintained at zero by its action, thus, the value of acoustic impedance z_2 is also zero and sound is perfectly reflected, although a compression is reflected as a rarefaction. Therefore, the secondary source provides a pressure release boundary condition and there is no transmission of sound downstream the secondary source.

The aim of this work is to avoid noise transmission through an aperture of an enclosure. We intend to attenuate acoustic pressure in the window area with an active noise control strategy. It will decrease that surface impedance and will avoid noise transmission through itself.

This technique has already been mentioned previously, and could be called active impedance control.[3] There are other works in which its results show that the net effect of the secondary loudspeakers consists of causing acoustic reflection. However, this effect has not been explicitly identified in this way.[4 - 6]

In order to decrease the sound pressure level at the transmission suface, local active control strategies are followed, because it is not necessary to reach a large area of attenuation. Our main objective is to achieve local attenuation at the window surface without any significative increase of sound pressure level in other areas of the enclosure.

Local active noise control

If sound pressure is cancelled in x_0 by means of a secondary source inside a room with diffuse sound field conditions, and the cancellation point is far from the secondary and the primary source, it is proved that the zone of quiet, within which the pressure is at least 10 dB below that due to the primary source, is a sphere with a diameter of about one-tenth of a wavelength[7]. On the other hand, it has been found that the space-averaged squared pressure in rooms with active control is higher than the value with only the primary field in operation.

A procedure to avoid that sound pressure level increases inside the room, consists of placing a secondary source next to the error microphone, so that the cancellation point is within the direct field of the secondary source. In this way the sound power level of the secondary source is low, compared to the primary source, and its contribution to the acoustic field amplitude in remote areas can be insignificant. This strategy is known as local active noise control. However, if the source is placed very near the error microphone, the diameter of the zone of quiet around the cancellation point tends to diminish.[8]

EXPERIMENTAL SET-UP

The experimental device is shown in figure 1 and 2, and it is composed by an enclosure with dimensions 1.2 x 1.5 x 1.1 metres. In a wall of the enclosure, there is an aperture of 0.3 x 0.3 metres, where it is intended to carry out the acoustic impedance control, and to avoid noise transmission from the interior of the enclosure to the exterior. This enclosure is placed inside a laboratory.

The cancellation point is in the middle of the window, where other four microphones (control microphones) are placed to evaluate the area of acoustic pressure attenuation. Likewise, seven microphones are also placed outside the enclosure, at a distance of one metre from the window, so that the emission decrease can be evaluated.

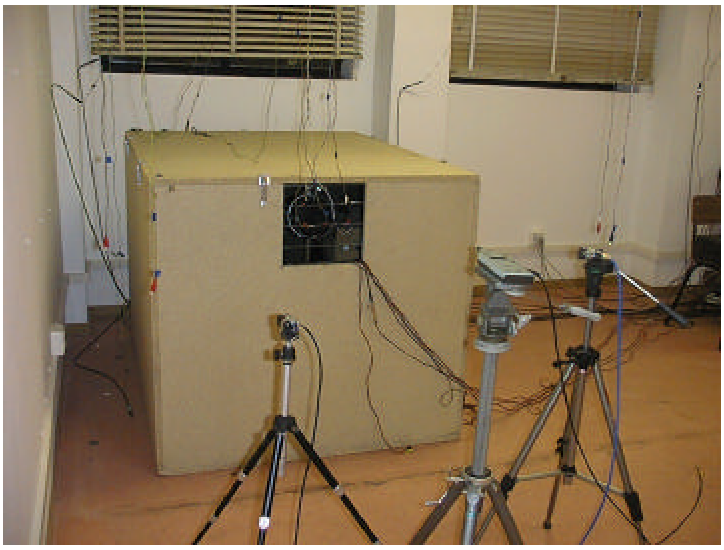

Figure 1. Experimental set-up.

Primary noise is generated by a primary loudspeaker placed inside the enclosure at the furthest corner from the window, in order to excite the highest number of modes of the enclosure. The secondary source is a loudspeaker with a radius of 6 cm and the active noise control system is a typical DSP with a feedforward structure with an adaptive control using the FXLMS algorithm. The reference signal is picked up straight from the function generator to avoid potential feedback contamination.

RESULTS

The experiences have been developed for pure tone sounds at frequencies between 100 and 2200 Hz, and with distances between secondary source and error microphone of r_{se} equals 15, 30 and 45 cm. R_i and R_e are defined as the space attenuation average of the microphones which were on the window and those placed outside the enclosure, respectively. A_i and A_e are the points were attenuation after control is detected, excluding the error microphone. Results of the experiences can be resumed in table 1. Negative values means increases of noise level.

From the results, it is easily observed how the tendency is the same for space averaged attenuations in window and outside the window, therefore the theory about acoustic impedance control as a method to avoid noise transmission by a specific boundary is confirmed. It can also be seen as the zone of quiet in the window tends, in general, to diminish as frequency increases.

Frequency		100	220	280	550	1100	2200
r_{se} = 15 cm	R_e	7.7	11.1	9.3	1.8	2.6	1
	A_e	7/7	7/7	7/7	5/7	6/7	5/7
	R_i	15.3	12.3	11.7	-0.4	3.3	-2.7
	A_i	4/4	4/4	4/4	2/4	3/4	0/4
r_{se} = 30 cm	R_e	110.7	4.8	6.6	9.1	3.2	-2.9
	A_e	7/7	7/7	7/7	7/7	5/7	1/7
	R_i	25.1	12.5	15.4	1.4	0.9	-7.9
	A_i	4/4	4/4	4/4	2/4	2/4	0/4
r_{se} = 45 cm	R_e	15.7	9.1	10	6.9	4.6	-10.9
	A_e	7/7	7/7	5/7	6/7	5/7	1/7
	R_i	22.3	22	12	2.2	-1	-7.1
	A_i	4/4	4/4	4/4	2/4	3/4	1/4

Table 1. Space average attenuation at window and outside the window.

The relationship between attenuation and r_{se} shows how, broadly speaking, at low frequencies, attenuation increases as r_{se} increases too. Nevertheless, at high frequencies, attenuation tends to diminish as r_{se} increases. These results are in concordance with theoretical expectation for the near field zone of quiet in the region of a piston secondary source.[2] Besides, some results suggest a relation between increments in the window and increments of noise level outside the enclosure, as it is shown in figure 3. Thus, it seems like the sound is more transmittet through "holes" of noisiest zones in the window.

Figure 2. Location of the sound sources and control microphones.

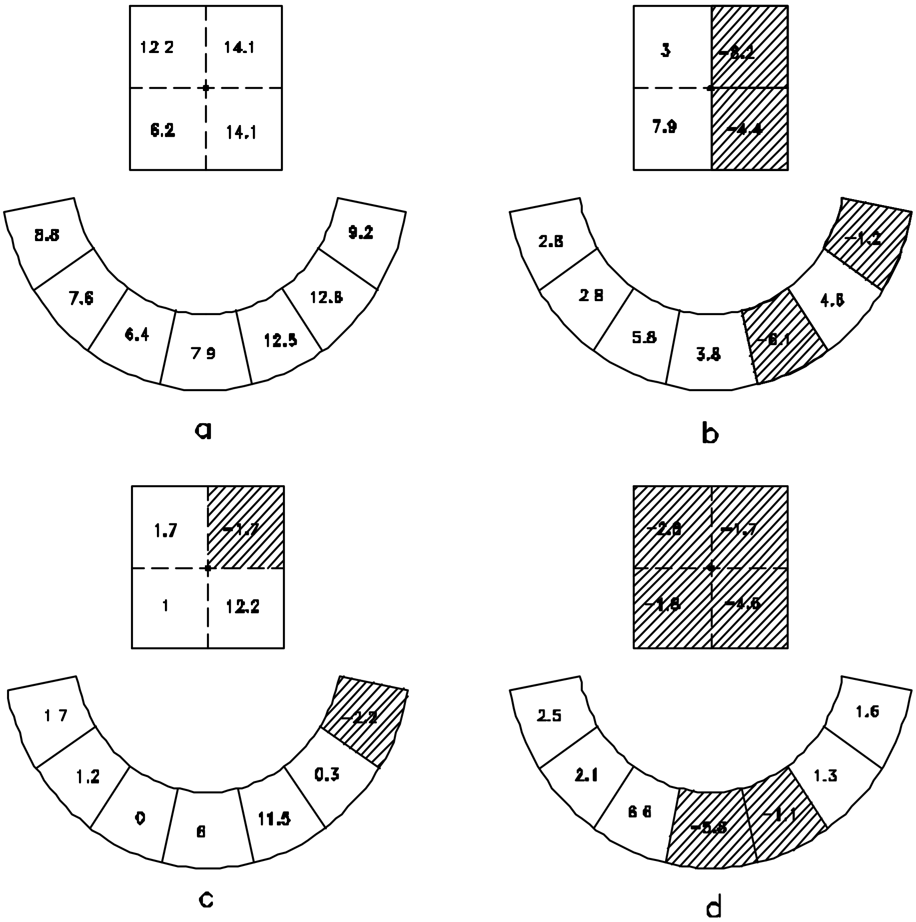

Figure 3. Attenuation levels in the window and outside the window, at the frequencies of a) 280 Hz, b) 550 Hz, c) 1100 Hz and d) 2200 Hz.

In an attempt to increase the extent of the zone of quiet, the pressure is cancelled at two points, which are separated by a distance less than 0.25λ. In this case, the zone of quiet is increased to an ellipsoid whose longest diameter is about a half of a wavelength.[9] The experience was carried out at 550 Hz and with a distance r_{se} equals 15 cm. The results are resumed in table 2, and it is shown how the extent of the zone of attenuation are increased, compared to results obtained with one error microphone.

	R_e	A_e	R_i	A_i
One error mic.	1.8	5/7	-0.4	1/4
Two error mic.	5.8	5/7	14.5	3/3

Table 2. Results at 550 Hz for one and two error microphones.

Eventually, experiences were carried out with a electric motor as the primary source, which main frequency emission was 220 Hz (Fig. 4). The reference signal was picked up straight from an accelerometer, placed on motor, and one error microphone was used, with r_{se} equals 15 cm. Results were R_e equals 10.1 and R_i equals 6.2, with attenuation detected in all the control microphones. Results were not as good as in case of loudspeaker as a primary source, but it was becuase motor noise level was lower than loudspeaker sound level, and the reduction could not be as high as with the loudspeaker as a primary source.

However this last experience showed how the strategie of active impedance control is able to work properly with noise caused by machinery.

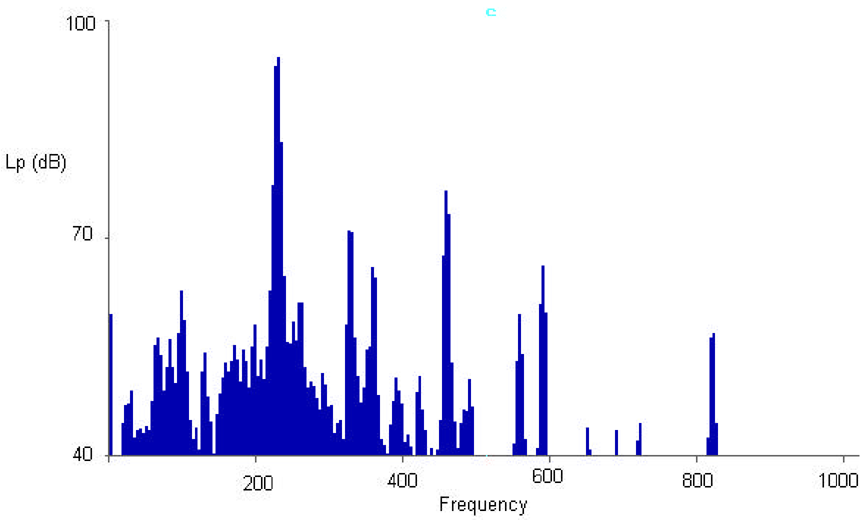

Figure 4. Noise spectrum of the electric motor.

CONCLUSIONS

As foremost conclusion, it is proved that sound pressure cancellation at the window implies emission attenuation through itself. The use of local techniques of active noise control allows the optimization of the attenuation area without causing significant increases in other areas of the enclosure. In the studied case it is confirmed that as the secondary source is approached to the error microphone, results tend to be worse due to the reduction of the zone of quiet.

This results show that it may be possible to reduce emission of industrial machinery, using an hybrid noise control system. The use of an enclosure around the machine can be combined with an active impedance control in ventilation windows or apertures for the materials supply.

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